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REVIEW OF THE NATIONAL AUTOMATED HIGHWAY SYSTEM RESEARCH PROGRAM

Committee for a Review of the
National Automated Highway System
Consortium Research Program

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Consortium Research Program**

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PREFACE

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) significantly expanded the role of the U.S. Department of Transportation (DOT) in research and development of intelligent transportation systems (ITS). In so doing, ISTEA called upon DOT to “develop an automated highway and vehicle prototype from which future fully automated intelligent vehicle-highway systems can be developed.”¹ DOT responded to this legislative mandate by budgeting approximately 10 percent of its ITS research and development funds for a National Automated Highway System research program aimed at evaluating and specifying a fully automated highway system for future deployment.

“Fully automated” driving—frequently characterized as “hands-off, feet-off” driving—has long been viewed by some researchers and technologists as an eventual outcome of developments in ITS. Full automation commonly is defined as requiring no control or very limited control by the driver; such automation would be accomplished through a combination of sensor, computer, and communications systems in vehicles and along the roadway. Fully automated driving would, in theory, allow closer vehicle spacing and higher speeds, which could enhance traffic capacity in places where additional road building is physically impossible, politically unacceptable, or prohibitively expensive. Automated controls also might enhance road safety by reducing the opportunity for driver error, which causes a large share of motor vehicle crashes. Other potential benefits include improved air quality (as a result of more-efficient traffic flows), increased fuel economy, and spin-off technologies generated during research and development related to automated highway systems.

The proposed benefits of full automation remain uncertain and continue to be the subject of debate, however. Some highway safety experts, for

¹ The complete language of the ISTEA provision appears in Chapter 1.

instance, believe that automated highway systems would have only marginal impact on overall highway safety, especially if these systems were deployed mainly on urban freeways and major commuter routes (which account for a relatively small share of the most serious motor vehicle crashes). Questions have been raised about the technical feasibility of implementing and maintaining automated systems that are tolerant to failure. Motorists' ability to use these technologies in a safe and effective manner also has been questioned. Some transportation planners and environmentalists have concerns about the secondary effects these systems might have: substantial increases in vehicle throughput could lead to higher total emissions and increased traffic congestion where automated and nonautomated roads merge. At another level, there are concerns about whether it would be fair and politically feasible to dedicate travel lanes to automated vehicles and whether the highway and automotive industries would accept the risk of developing and introducing automation technologies, given the liability uncertainties.

In response to the congressional mandate for prototyping and testing of an automated highway system by 1997, DOT research was focused in a consortium of public- and private-sector organizations drawn from academe and from the automotive, highway, electronics, and communications industries. Such a partnership was expected to offer a level of resources and range of perspectives necessary to address the many technical, economic, and societal issues raised by full automation and provide the leadership needed to build enthusiasm for the early selection of a preferred system configuration.

The National Automated Highway System Consortium (NAHSC) began work in October 1994 with nine core members: Bechtel Corporation, the California Department of Transportation, Carnegie Mellon University, Delco Electronics Company, General Motors Corporation, Hughes Electronics Corporation, Lockheed Martin Corporation, Parsons Brinckerhoff, Inc., and the University of California at Berkeley's Partnership for Advanced Transit and Highways (PATH) Program. This consortium was charged with evaluating alternative automated highway system concepts and specifying, prototyping, and testing a "preferred" automated highway system that would serve as the basis for the development of future automated highway systems.

The consortium staged a public demonstration of automated vehicle and highway technologies in August 1997. The next item on its agenda was completing the process of selecting and testing a preferred automated highway system. In the meantime, however, DOT had indicated its intention to de-emphasize the selection of a system specification and focus instead on the development and deployment of nearer-term intelligent vehicle technologies, such as collision warning systems. This successor program, the Intelligent Vehicle Initiative (IVI), would reshape and further integrate several advanced vehicle, highway, and transit research and development programs under way

within the National Highway Traffic Safety Administration, the Federal Transit Administration, and the Federal Highway Administration.

STUDY CHARGE AND ORGANIZATION OF REPORT

As these changes were being debated, DOT's ITS Joint Program Office asked the National Research Council—under the auspices of the Transportation Research Board and with assistance from the Computer Science and Telecommunications Board—to convene a study committee to assess the appropriateness of the original vision and mission of the National Automated Highway System Research Program, the consortium's results and the effectiveness of the approach taken by NAHSC in carrying out its charge, and the role of the consortium in future research on intelligent vehicles. Specifically, the study committee was asked to address four questions:

1. Given what has been learned to date about the technical, societal, institutional, and economic feasibility of an automated highway system, is the National Automated Highway System Research Program vision and mission still appropriate and worthy of major research investment?
2. Are there elements of this research that should be continued in the Intelligent Vehicle Initiative, which focuses on a nearer-term horizon?
3. In representing a new approach for conducting research and development, has NAHSC been effective and efficient?
4. Is there an appropriate role for this consortium in the Intelligent Vehicle Initiative?

Under the leadership of Arden L. Bement, Jr., Basil S. Turner Distinguished Professor of Engineering at Purdue University, and Herbert H. Richardson, Associate Vice Chancellor for Engineering and Director of the Texas Transportation Institute at Texas A&M University, a committee of experts was convened from the fields of transportation planning and operations, communications and information systems, traffic safety and human factors, vehicle design and production, and transportation research policy and management. The study committee held its first meeting in conjunction with the NAHSC demonstration of technologies in San Diego, California, in August 1997. Two additional committee meetings were convened in the fall of 1997. During the course of its deliberations, the study committee heard from a number of individuals from the automotive, trucking, insurance, and highway industries, as well as the safety and environmental communities (see Appendix B). Committee members also interviewed program staff from several of the organizations in NAHSC and invited the consortium's management to brief the committee on its procedures, accomplishments, and work plan. These discussions were invaluable to the committee in respond-

ing to the questions DOT posed. At the outset of the study, the committee debated the study scope and whether it should go beyond the specific questions asked by DOT. The committee elected, however, to adhere closely to the charge set forth by the sponsor. The project's accelerated time schedule precluded a more complete evaluation of automated highway system technologies and options for furthering their development and implementation. This report, therefore, is intended to be a program review rather than a critique of specific technologies. Nevertheless, the committee anticipates that its conclusions concerning the National Automated Highway System Research Program will have broader application within the ITS program.

The committee's responses to the foregoing questions appear in Chapter 1 of this report. The remainder of the report provides support and background for these responses. Chapter 2 examines the history of interest in automated vehicle and highway systems, including the events leading up to the creation of the National Automated Highway System Research Program. Chapter 3 takes a closer look at two key transportation needs—reducing the number of motor vehicle crashes and relieving traffic congestion—that often serve as rationales for the development of automated vehicles and highways. This chapter also describes various vehicle and highway automation concepts, from partially to fully automated (hands-off, feet-off) driving. Chapter 4 reviews the history, organization, and accomplishments of NAHSC in carrying out its charge to demonstrate and specify an automated highway system. Key findings from the report, which provide the basis for the study committee's responses to DOT's questions, are summarized in Chapter 5.

This report has been independently reviewed according to the procedures of the National Research Council's Report Review Committee. Reviewers were chosen for their diverse perspectives and technical expertise; they were asked to provide candid and critical comments to assist the study committee and the Research Council in making the report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. (The contents of review comments and the draft manuscript remain confidential to protect the integrity of the deliberative process.) The study committee thanks the following individuals for their participation in the review: Barry W. Boehm, University of Southern California; Alexander H. Flax, Potomac, Maryland; Lester A. Hoel, University of Virginia; Craig Marks, Allied Signal, Inc. (retired); John L. McLucas, Alexandria, Virginia; Robert M. Nicholson, National Highway Traffic Safety Administration (retired); Joseph L. Schofer, Northwestern University; C. Michael Walton, University of Texas; David L. Winstead, Maryland Department of Transportation. Although these individuals have provided many constructive comments and suggestions, responsibility for the final content of this report rests solely with the study committee and the National Research Council.

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EXECUTIVE SUMMARY

The National Automated Highway System Research Program was begun in 1992 in response to a legislative mandate for the development of an automated highway system prototype and test track by 1997. To assist it in carrying out this mandate, the U.S. Department of Transportation (DOT) created the National Automated Highway System Consortium (NAHSC) in 1994, enlisting the participation of nine leading organizations from academe and the motor vehicle, highway, electronics, and communications industries. Envisioning a fully automated, “hands-off, feet-off” system that would greatly enhance highway safety and capacity, DOT charged NAHSC with staging a public demonstration of automation concepts and technologies within 3 years. The demonstration, held in San Diego, California, in August 1997, fulfilled this mandate. DOT also charged NAHSC with specifying a preferred automated highway system for future development and deployment. This goal was to be accomplished within 7 years.

Three years into the program, DOT asked the Transportation Research Board to convene an independent study committee to review the overall vision and mission of the National Automated Highway System Research Program, as well as the findings, performance, and future role of NAHSC. During the course of the committee’s 7½-month assessment, DOT withdrew financial support from NAHSC. This decision apparently was driven by a desire on the part of the DOT to shift its priorities to encouraging adoption of nearer-term, safety-oriented technologies; it was hastened by a shortfall in research funds caused when the Intermodal Surface Transportation Efficiency Act expired in late 1997 and was extended temporarily by Congress. After critically examining the vision, mission, and approach of the National Automated Highway System Research Program in general, the study committee concurs with this decision.

Although Chapter 1 of this report contains a full explanation, the study committee’s reasoning can be reduced to three fundamental issues:

- ◆ The task given to NAHSC of developing, evaluating, and selecting a preferred specification for a fully automated highway system in only 7 years was unlikely to be achieved because daunting technical, social, and institutional issues must be addressed and resolved.

- ◆ NAHSC was given dual, but conflicting, responsibilities: to promote a shared vision of automated highways and to objectively evaluate the prospects of addressing and overcoming the many complicated challenges arising in attempting to realize this vision.

- ◆ The consensus-based management and decision-making structure of NAHSC (as required by DOT) made it very difficult for the consortium to respond to changing government funding levels and priorities—as well as the results of some of its own research indicating the need for changes in program direction.

Despite its conclusion that the National Automated Highway System Research Program should not be continued, the study committee believes that the creation of NAHSC was a bold and innovative attempt to meet the nation's long-term highway capacity and safety needs. These needs are genuine and growing and will only worsen if neglected. Technology will be important to meeting these needs, and government-industry consortia offer a promising approach to bringing together the many public and private entities that must cooperate to integrate vehicular, computer, telecommunications, and other necessary technologies.

As DOT shapes future research and development initiatives on intelligent transportation systems, the committee urges it to

- ◆ Continue to explore opportunities for vehicle-to-vehicle and vehicle-to-infrastructure cooperation as part of long-range research aimed at meeting future transportation safety and capacity needs;

- ◆ Ensure that human factors considerations are thoroughly integrated into program plans and are prominent at all stages of research, development, and deployment;

- ◆ Independently evaluate the technical work of NAHSC and ensure that its findings are well documented for the benefit of future research and development efforts in this field;

- ◆ Continue to pursue public- and private-sector partnerships, while learning best practices and alternative organizational approaches from other collaborative activities; and

- ◆ Seek external, independent reviews of the mission, objectives, and progress of all major research and development initiatives.

Each of these recommendations is discussed at the conclusion of Chapter 1.

1

RESPONSES AND RECOMMENDATIONS

The U.S. transportation sector faces important challenges. Foremost among these challenges is the need to enhance the safety and capacity of the nation's highway system. In 1993, then Federal Highway Administrator Rodney E. Slater noted, "Our current highway transportation, as effective and elegant as it is, is at a critical crossroads in its evolution and has started to plateau in its ability to provide significant new operating performance in its present form."¹ Safety gains are becoming increasingly difficult to achieve, and the capacity of the system is being strained by growing demands for passenger and freight transportation. There is a pressing need for innovative approaches to meeting these challenges.

Intelligent transportation systems (ITS) represent one such approach—offering, as Slater remarked, the potential for "substantial performance improvements in this and in coming decades." Recognizing the possibilities of ITS and seeking to accelerate development and deployment, Congress authorized more than \$650 million over 6 years for ITS research and demonstration projects in the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA). Congress appears to have seen far-reaching potential in ITS, foreseeing a highway transportation system that is not only more efficient and convenient—thanks to emerging technologies for traffic management, traveler information, and route guidance—but safer because of advanced products that enhance driver awareness and intervene with emergency controls to help motorists avoid crashes. The ultimate application of ITS would be the advent of fully automated vehicles and highways that would turn routine driving tasks over to computer, communications, and information systems; bring about highly orchestrated and more-efficient traffic flows; and lead to substantial gains in system safety, capacity, efficiency, and comfort.

¹ Appendix A contains the full text of Administrator Slater's October 1993 speech announcing the U.S. Department of Transportation's (DOT) intention to establish the National Automated Highway System Consortium.

The notion of fully automated driving is not new; it stems from visions of hands-off, feet-off driving that extend back more than 50 years. As demands for safety and mobility have grown and technological possibilities have multiplied, however, interest in automation has been rekindled. Seeking to accelerate the development and introduction of fully automated vehicles and highways, Congress legislated in ISTEA that

The Secretary [of Transportation] shall develop an automated highway and vehicle prototype from which future fully automated intelligent vehicle-highway systems can be developed. Such development shall include research in human factors to ensure the success of the man-machine relationship. The goal of this program is to have the first fully automated roadway or an automated test track in operation by 1997. This system shall accommodate installation of equipment in new and existing motor vehicles. [ISTEA 1991, Part B, Section 6054(b)]

In mandating the development of an automated vehicle-highway prototype and the first fully automated roadway by 1997—interpreted as requiring the demonstration of a fully automated highway system—ISTEA prompted the transportation and research communities to consider how a fully automated system might one day emerge. Traditionally, new highway transportation technologies are developed and introduced through incremental changes in the system, as new products are added, refined, and merged.² Following this traditional course, increasingly automated vehicles and highways might emerge over time as a result of the gradual introduction and integration of ITS products. ISTEA's requirement for prototyping a fully automated vehicle and highway, however, prompted consideration of an accelerated path to implementation of fully automated systems.

ISTEA inspired a vision of fully automated driving made possible relatively quickly as a result of concerted efforts to evaluate, test, and publicize alternative system concepts. The preferred system selected through this process would shape the future development and deployment of automated driving technologies. With this vision in mind, DOT established the National Automated Highway System Research Program. The stated mission of the program was to “specify, develop, and demonstrate a prototype automated highway system” that would “provide for progressive development that can be tailored to meet regional and local transportation needs” (DOT 1993). To focus and drive this effort, DOT called for a public-private partnership.

The National Automated Highway System Consortium (NAHSC) was created in late 1994. DOT viewed the consortium—which comprised nine leading organizations from academia and the motor vehicle, highway, electron-

² Even the advent of the Interstate Highway program in 1956, often described as revolutionary, was preceded by years of experience in designing, building, and operating divided and limited-access toll roads, turnpikes, and parkways. This experience enabled the federal government and states to develop and agree upon specifications for modern Interstate freeways.

ics, and communications fields—as critical to enriching the program’s expertise and resources. In the diverse and decentralized transportation sector, such cooperation and leadership also were deemed essential to garnering the extensive industry and government support and enthusiasm needed to reach early agreement on the kind of system that would influence the design, development, and deployment of automation capabilities for many decades.

To achieve its Congressional mandate, DOT directed NAHSC to examine alternative system concepts—ranging from those that would provide full automation through sensors, computers, and other instrumentation installed primarily in vehicles to those that would require integrated instrumentation of vehicles, highways, and other infrastructure. In doing so, DOT asked the consortium to assess the technical feasibility and the economic, institutional, and social implications of alternative system concepts. These matters were to be examined with high regard for the views of public- and private-sector transportation users and providers, termed “stakeholders.” To elicit this input and to build interest in fully automated vehicles and highways, the consortium also was directed to undertake outreach, promotional, and public relations efforts. NAHSC also was asked to make all of its key decisions on the basis of consensus opinion of its stakeholder members (DOT 1993, 14). The congressionally mandated demonstration scheduled for 1997 was to be the centerpiece of the program’s efforts to showcase and build support for a fully automated highway system.

In late 1996, however—less than 3 years after calling for the creation of the consortium and while the technology demonstration was still being planned—DOT began rethinking the program’s emphasis on and ability to achieve the early specification of a fully automated system. DOT was shaping a new program, the Intelligent Vehicle Initiative (IVI), that would emphasize the evaluation and introduction of advanced vehicle control and driver assistance features that could be deployed in the next decade. Initial plans called for government and academic researchers, collaborating in various ways with industry, to evaluate, test, and encourage the introduction and integration of the features offering the largest safety gains and other benefits to the public. Under IVI, the earlier target of fully automated driving would be de-emphasized.

In view of these developments, DOT’s ITS Joint Program Office requested the establishment of a study committee by the National Research Council to address specific questions concerning the appropriateness of the original vision and mission of the National Automated Highway System Research Program, the achievements and effectiveness of NAHSC in carrying out its mission, and the prospective role of the consortium in DOT’s new intelligent vehicle program. In December 1997—during the course of this study—DOT indicated its intention to withdraw financial support from NAHSC and concentrate its resources on IVI. The committee nevertheless believes a retro-

spective critique of the National Automated Highway System Research Program and NAHSC will prove valuable. Public and private partnerships will continue to command national attention, and they have vital roles in ongoing ITS development and deployment.

COMMITTEE RESPONSES

Given what has been learned to date about the technical, societal, institutional, and economic feasibility of an automated highway system, is the National Automated Highway System Research Program vision and mission still appropriate and worthy of major research investment?

The legislative mandate for a prototype automated vehicle-highway system prompted DOT to envision the early introduction of a fully automated highway system. NAHSC, which was created to fulfill this vision, was directed to demonstrate full-automation technologies and scenarios in less than 3 years and to identify, demonstrate, and select a preferred fully automated highway system within 7 years. Selection of the preferred system would involve active outreach to transportation users and providers to reach agreement on the most suitable system configuration. Once a preferred system configuration had been identified, more concerted efforts to develop, test, and deploy it were envisioned.

This vision was ambitious from the outset. The study committee believes that the concerted efforts of the past 3 years have revealed limited prospects for a fully automated system to be selected in such an accelerated manner. NAHSC vigorously pursued its mission to identify, assess, and promote a preferred fully automated highway system. In the study committee's view, however, this mission was overly optimistic and has proved unachievable.

The condensed time frame for the consortium's work was especially optimistic—and proved problematic. The 1997 demonstration, which was largely ancillary to the end mission of the program, detracted from the consortium's ability to evaluate many of the technical, societal, and institutional issues associated with fully automated highway systems. Budgetary cutbacks caused by reduced government funding exacerbated these difficulties. Even under better circumstances, however, the study committee doubts whether many of the complex issues associated with fully automated driving could have been addressed adequately to support early identification and specification of a preferred system.

Individual members of the study committee differ about whether fully automated vehicles and highways eventually might emerge to significantly improve highway safety and capacity, but they agree that such outcomes

could happen only over time because of the technological changes that would ensue and the many societal, institutional, and economic issues that would have to be recognized, debated, and decided through public policy and political processes. The highway transportation system has become integral to the daily lives of Americans and the national economy. A fully automated highway system with the potential for important safety, social, and environmental effects, as well as changes in public- and private-sector responsibilities, would require careful consideration and debate before a preferred system could be identified for widespread acceptance and adoption. Failure to fully recognize these issues and the processes needed to vet them publicly was a major shortcoming of the National Automated Highway Research Program.

The difficulty of building an early consensus on a fully automated system was underscored by the consortium's own experience and work. Its preliminary results, for instance, suggested the importance of operating fully automated vehicles on dedicated lanes to manage safety and maximize traffic throughput. Many state and local transportation officials consulted by the consortium were skeptical, however, about the prospects of adopting such a system. These officials expressed concern about the expense and political difficulties of investing in facilities devoted exclusively to fully automated vehicles and making large-scale changes to the well-established transportation infrastructure. Environmentalists, planners, and land use experts consulted by the consortium raised concerns about the overall effects on vehicle emissions, energy use, and urban development patterns that could result from deploying fully automated highway systems that increase travel and traffic volumes. Motor vehicle manufacturers, their suppliers, and insurers questioned whether tort liability issues raised by such systems have been adequately explored to warrant optimism about the prospects for accelerated system development and deployment.

As these and other challenges presented by full automation have become more evident, the kind of broad and deep support needed to reach agreement on a fully automated highway system has failed to build within the transportation community—further revealing the limited prospects for NAHSC to achieve its mission. At a minimum, the early identification of a preferred fully automated highway system promising to have large and lasting effects on the transportation system would require a broad-based commitment from leaders in the public and private sectors of the transportation community. Indeed, DOT recognized the need for such a consensus at the inception of the program. Outreach, promotional, and public relations activities were emphasized as part of the consortium's role and were considered central to the 1997 demonstration. The lack of broad-based support as the program proceeded, despite active promotional and outreach efforts, was indicative of the limited prospects for gaining consensus.

In light of not only the analytical work undertaken by the consortium but the complex challenge it encountered in trying to assess and build support for fully automated highways in the far-reaching transportation sector, the original vision of fully automated systems emerging in a preplanned, accelerated manner seems less plausible than it did 3 years ago. In the study committee's view, it would be unwise to continue efforts aimed at early specification of a preferred fully automated highway system. Nevertheless, the committee recognizes that many transportation needs can be addressed only through persistent and systematic research. DOT must continue to explore and examine transportation needs and solutions over longer time horizons and from system-level perspectives that encompass the vehicle, the highway environment, and the driver.

Are there elements of the National Automated Highway System Research Program that should be continued in the Intelligent Vehicle Initiative, which focuses on a nearer-term horizon?

DOT is placing increased emphasis on safety, as its most recent strategic plan indicates (DOT 1997). The early development and deployment of transportation technologies that promise near-term safety benefits therefore have taken on greater priority within DOT's ITS program in general. The study committee does not question this change in emphasis but believes that it should be accompanied by—and not preclude—research and development aimed at addressing longer-range highway capacity, safety, and efficiency needs that face the nation.

It is premature to comment definitively on the mission and methods of IVI, which is still being shaped. Nevertheless, any major research initiative aimed at furthering intelligent vehicle and highway systems should have certain characteristics. Most importantly, the need for the program and its mission must be defined and well conceived at inception to ensure that time and resources are well spent. Effective strategies for influencing developments in a diverse, global, multibillion-dollar motor vehicle manufacturing industry, and the need for exerting such influence, require careful and critical consideration. This report urges DOT to seek external and independent reviews of its major research initiatives to foster such reflection. The experience of the National Automated Highway System Research Program has demonstrated the importance of such an approach, not only in defining a program's mission and structure but in shaping process and content. As an example, the study committee believes that major research initiatives must employ a systems approach to be valid and effective. For instance, human factors assessments must be integrated into the design, engineering, and testing stages of technology development to ensure safe and effective interactions among drivers, vehicles, and infrastructure. Institutional, liability, and societal bar-

riers to implementation and the safety, reliability, and cost of the technologies must be actively investigated to inform public policy. In subsequent research programs, such issues should not be neglected or repeatedly deferred because of their complexity and controversy—nor should they be underestimated as quickly resolvable.

The National Automated Highway System Research Program would have benefited from earlier outside guidance and criticism; independent, retrospective evaluations of its technical work are still needed, however. The consortium's experience and work has enhanced the transportation community's understanding and recognition of the numerous technical and practical issues associated with fully automated vehicles and highways. To provide a foundation for follow-on research, this work—including the San Diego demonstration—should be objectively and thoughtfully examined. The ISTEA requirements were interpreted as requiring a technology demonstration that would stimulate the public's imagination. Thus, the 1997 San Diego demonstration was designed more to display, rather than assess, automated highway system capabilities. Nevertheless, the staging of the demonstration entailed extensive and creative engineering, planning, and field evaluations, involving thousands of miles of automated vehicle travel during vehicle and system testing, certification, and operations. These efforts should be examined in light of the rare opportunity they presented to gauge the capabilities and compatibilities of different automation technologies in a controlled yet complex setting of vehicles, roadways, and passengers. Technical and practical insights gained from this unprecedented experience should be captured for the benefit of future research.

Apart from the demonstrations, NAHSC devoted a great deal of effort to assessing automation concepts and enabling technologies from a broad perspective, developing evaluation frameworks that could prove useful for examining long-range and systemwide implications and requirements of automated vehicle and highway technologies. For instance, the consortium examined safety, throughput, and public infrastructure effects for several automated highway system concepts that allocate sensing, computing, and communications responsibilities differently among vehicles and infrastructure. These kinds of generic, system-level assessments can be helpful in identifying important issues that will warrant early consideration as automation capabilities are developed.

Although a thorough examination of the specific projects undertaken by NAHSC was outside the scope of this study, the study committee agrees that certain general areas of research explored by the consortium—such as opportunities for vehicle-to-vehicle and vehicle-to-infrastructure interaction—warrant continued investigation in follow-on programs. An independent review and documentation of the consortium's experience, methods, and findings undoubtedly will point to significant contributions in these areas.

In representing a new approach for conducting research and development, has NAHSC been effective and efficient?

DOT's decision to establish NAHSC was bold and innovative, as was the decision of the nine public, private, and academic organizations to participate. Subsequent unreliability in federal funding reduced the program's luster and proved disruptive and financially troublesome. The study committee believes, however, that several conflicts built into the consortium's role and structure would have hindered its effectiveness even in the absence of these funding shortfalls.

Most significant was the conflict presented by the consortium's dual responsibilities for evaluating and promoting fully automated highway systems. NAHSC's ability to fully and critically evaluate automated systems was susceptible to criticism in light of its promotional role. Moreover, the latter role entailed a highly inclusive, consensus-building structure that limited program flexibility and complicated management. This structure proved especially burdensome when modifications to the program appeared warranted in response to reductions in budgets, changes in government priorities, and early feedback and findings about the difficulties involved in assessing, building support for, and selecting a fully automated highway system specification. Moreover, it is doubtful that DOT, acting as both a member of the consortium and its overseer, could offer objective and consistent policy guidance.

The conflicts built into this collaborative process hindered the consortium's effectiveness and efficiency. The mixing of evaluation and promotional roles affected the quality of the consortium's analyses and the conclusions it drew based on the tentative results from this work. Blended together, neither role could be performed effectively and efficiently. The consortium's fixed membership, pre-allocated budgets, and consensus decision-making process slowed its responsiveness and proved burdensome for program management. Arguably, no amount of restructuring or reconstituting of the consortium to improve its efficiency would have made its mission any more achievable. Nevertheless, important insights can be gained from the way this program was planned, structured, and directed.

Collaborative arrangements that combine the perspectives and resources of the public and private sectors will continue to be essential to ITS research, development, and deployment. These arrangements facilitate shared commitment and risks while providing access to a diversity of technologies, ideas, expertise, and financial resources. They also can forge links between organizations and industries that can have a lasting impact on how transportation technologies are developed and introduced. Other, more flexible, kinds of partnerships and cooperative arrangements, however, may be better suited for evaluation, development, and promotional functions. Best practices can be identified by studying past and ongoing collaborations between the public and private sectors. NAHSC's approach—including its responsibilities, its

organizational structure, its internal and external funding arrangements, and its relationship with DOT—should be examined in light of the experiences of other collaborative efforts. Such an evaluation was not possible within the time frame and scope of this review. Nevertheless, the lessons learned from undertaking such an assessment undoubtedly would prove valuable in shaping the public- and private-sector partnerships that will be essential to ITS.

Although the focus of this review has been the National Automated Highway System Research Program, broader implications can be drawn from the responses given to the four questions posed by DOT. The study committee believes that the conclusions drawn from this review should form the basis for continuing deliberations on best practices for future government-industry consortia.

Is there an appropriate role for the consortium in the Intelligent Vehicle Initiative?

DOT originally established NAHSC with a mission, composition, and set of procedures aimed at evaluating and building consensus for the early specification of a fully automated highway system. DOT now is focusing its efforts on the development and testing of intelligent vehicle technologies that have the potential for nearer-term application. Although some of NAHSC's individual members may be well suited for this new emphasis, the consortium as a whole—as it has been constituted and organized—is not.

GENERAL OBSERVATIONS AND SUMMARY OF RECOMMENDATIONS

In a diverse and democratic society, it is difficult to reach consensus about which needs warrant attention by government and how they should be addressed. In retrospect, the mission of the National Automated Highway System Research Program proved unachievable, not only because of the daunting technical, institutional, and societal issues that would need to be addressed but also because the needs justifying this accelerated approach were not made evident. Some of the fundamental difficulties arising in pursuit of this mission might have been foreseen at the inception of the program by posing questions about the program's goals and process. For example, is it plausible to expect fast-track attainment of a technological outcome that would involve many complex societal, institutional, and technical issues? To what extent can evaluation and advocacy be mixed? Can a federal agency serve effectively as a program's sponsor, active participant, and overseer? Such reflective questions were not asked at the outset of the program—for instance, as a central element of the precursor phase—suggesting the need for early and frequent program reviews by third parties that compel such discipline.

The tenor of this review should not be construed as critical of further efforts to undertake research on vehicle and highway automation with a long-range and systems perspective. Information and communications technologies undoubtedly will play an increasingly important role in meeting the nation's transportation safety and mobility needs. Defining, sponsoring, and ensuring continuity of funding for such long-range and system-level research remain critical to the mission of DOT and the federal ITS program. The following general recommendations, distilled from the committee's responses to DOT's four questions, underscore this sentiment.

Exploration of opportunities for vehicle-to-vehicle and vehicle-to-infrastructure interaction to meet long-term transportation safety and capacity needs should continue.

Early specification of a fully automated highway system is an inappropriate research goal. Nevertheless, exploration of advanced vehicle and highway technologies and their possible coordination and interaction to meet long-term transportation safety and capacity needs should continue to have a place in the ITS program. Such long-range research should be guided by a strategic plan that attempts to define the responsibilities of the vehicle and infrastructure in ITS. Doing so will raise many questions—for instance, about the respective roles of the public and private sectors—that an ITS research program should be designed to address.

Human factors should be thoroughly integrated into advanced vehicle and highway research, development, and deployment.

Human factors considerations—that is, the behavior and capabilities of drivers—must have a central role in shaping advanced vehicle and highway technologies and ensuring their safety and use. Driver behavior and performance should not be treated as side issues or addressed in a perfunctory manner; they must be repeatedly and comprehensively incorporated into technology design, development, and evaluation processes.

The work of the National Automated Highway System Research Program should be evaluated and documented.

From its technology demonstrations and concept analyses to its workshops, outreach efforts, and consultations with transportation system users and providers, NAHSC has fostered interest in and debate about vehicle and highway automation. It also has yielded many technical insights. This experience and work should not be ignored. DOT should sponsor an independent review of the consortium's methods, results,

and conclusions, including other findings and conclusions that can be drawn from this effort. The results should be documented and made accessible to the ITS community to help build a foundation for future work in this area.

Public- and private-sector collaborations should continue to be pursued.

NAHSC has demonstrated the potential value and possibilities of cooperation between the public and private sectors of the diverse transportation and technology communities. The conflicts that were inherent in the consortium's approach, however, illuminate the importance of carefully evaluating collaborative options to ensure compatibility with the program's intended purpose. Public- and private-sector cooperation will be essential to ITS development and deployment, ensuring product compatibilities while expanding ideas, resources, and interest. Many collaborative efforts are under way in the transportation sector. DOT should systematically study these activities to identify the best practices and approaches for use in ITS.

External, independent reviews of research programs should be sought.

External review committees often are established to offer independent advice about the mission plans of a research and development program and to critique progress toward goals and objectives as the program proceeds. Such external reviews have proved valuable in many government and industry research programs; they should have been undertaken as part of the National Automated Highway System Research Program. External reviews should accompany future research initiatives on advanced vehicle and highway systems, as well as other ITS programs.

REFERENCES

ABBREVIATION

DOT U.S. Department of Transportation

DOT. 1993. *Request for Applications to Establish a National Automated Highway System Consortium*. Number DTFH61-94-X-00001. December 15.

DOT. 1997. *Department of Transportation Strategic Plan 1997 to 2002* (also available on DOT World Wide Web home page, <http://www.dot.gov>).

2

BACKGROUND

A review of the history of interest in fully automated vehicles and highways is important in helping to explain why the U.S. Department of Transportation (DOT) has been pursuing two different visions of how a fully automated system might one day emerge. One vision is of increasingly automated vehicles and highways evolving into a fully automated system relatively gradually through efforts to encourage developments in intelligent vehicle technologies and intelligent transportation systems (ITS) in general. The other envisions a fully automated highway system emerging sooner, facilitated by deliberate efforts to specify a system configuration and to encourage development and implementation of that system. Having pursued both visions during the past 5 years, DOT now has indicated its intention to consolidate its research efforts to realize a single vision.

INTEREST IN FULLY AUTOMATED VEHICLES AND HIGHWAYS

Fully automated driving has been an aim of engineers, planners, and technologists for decades. As early as 1939, the World's Fair in New York included a futuristic exhibit by General Motors (GM) on "driverless" cars (Shladover 1990, 158). During the 1950s, GM research engineers conceptualized and conducted preliminary tests of automobiles with steering and speed controlled by radio controls and other mechanical systems (DOT 1995, 73). GM's early work envisioned fully automated, hands-off, feet-off systems that would greatly increase driver convenience and comfort: Drivers were portrayed as relaxed, cruising in completely automated cars down the open freeways created by the newly established Interstate Highway System while they read the newspaper and drank coffee. Increased safety and highway capacity had yet to be emphasized.

By the 1960s, automation concepts were being explored not only as a means of enhancing driving comfort and convenience but also with other, more practical, applications in mind. For instance, researchers at Ohio State

University—motivated by the emerging network of modern freeways and advances in transistors and other radio and communications technologies—investigated vehicle and roadside communications devices that would assist motorists in performing some driving tasks and provide real-time traffic and navigation information.¹ Fully automated highway systems were increasingly being regarded as a way to increase throughput on increasingly congested urban and intercity highways. During the late 1970s, GM received DOT funding to examine fully automated highway system concepts and identify an optimal system configuration that could be developed and deployed before the end of this century (DOT 1980; DOT 1981). Although federal funding of these efforts was discontinued in 1980, this general approach—that is, the goal of early system specification and deployment—would be rejuvenated during the 1990s.

A new emphasis emerged, however, in the late 1980s. Although work on fully automated systems continued through the decade, increased attention was being given by the public and private sectors to intelligent, partially automated products and services.² Advances in electronics, sensor, and computing technologies—and burgeoning activity in ITS—generated commercial interest in products that might enhance driver perception as well as driving capabilities: for example, by sensing an impending collision, alerting the driver, and applying the brakes if necessary. Motorists might be aided further by traveler information and route guidance systems being developed as part of ITS. Full automation concepts—typically imagined as hands-off, feet-off driving on instrumented highways—were the subject of intermittent research but generally were viewed as long-range outcomes of the gradual development and expanded use of nearer-term intelligent vehicle and highway products.

ITS AND THE VISION OF INCREASINGLY AUTOMATED SYSTEMS

ITS is the collective term for a variety of advanced surface transportation technologies that are intended to aid driving, enhance the capacity and efficiency of the highway system, and assist transportation agencies in managing their facilities and controlling traffic. The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) substantially increased federal funding of

¹ The traveler information system that was the subject of research from the 1960s to the early 1970s was known as the Electronic Route Guidance System (Rosen et al. 1970).

² Efforts to coordinate ITS development at the national level began with Mobility 2000, a voluntary organization formed in the late 1980s to bring together advocates for intelligent vehicle and highway systems (IVHS) from the private and public sectors and from academe (Texas Transportation Institute 1990). Mobility 2000 was subsumed by IVHS America, later renamed ITS America.

ITS research, development, and implementation. There was a strong rationale for expanded funding. By the end of the 1980s, construction of the Interstate Highway System was nearly complete, yet traffic demands on the nation's highway network were continuing to grow at an extraordinary pace. Building more roads clearly was not the solution in many areas where costs and traffic disruptions would be prohibitive. Emerging technologies were regarded as critical tools for keeping pace with growing demands for system efficiency and safety (Saxton 1993). Among other benefits, these technologies promised to optimize traffic signal timing, advise motorists about traffic conditions, enable rapid detection and removal of accidents and other obstacles to traffic flow, and reduce waits at toll and weigh stations.

Implicit in the ITS provisions of ISTEA was the need for the private and public sectors to work together in developing, demonstrating, and deploying intelligent transportation systems and technologies to accelerate their availability. ISTEA called upon DOT and the ITS research community to develop a strategic plan for embarking on an efficient and effective course of ITS development, deployment, and operations [ISTEA, Section 6054(a)]. The DOT and the ITS America³ strategic plans foresaw an integration of ITS products and services (DOT 1992; ITS America 1992). Both DOT and ITS America expected that with the assistance of public and private partnerships, ITS would be implemented incrementally but in a coordinated manner that would facilitate systems compatibility among regions and the gradual integration of different ITS products and services. This thinking, sometimes called a “planned evolution,” is typified in a passage from the strategic plan of ITS America: “As our base of knowledge and technology grows, as we find out what works best, what the market will support, and what prudent management demands, the systems will expand and mature, taking on a national character” (ITS America 1992, II-6).

The ITS America and DOT strategic plans identified five “functional areas”—essentially groupings of ITS products that would provide similar or compatible services. For example, one functional area, advanced vehicle control systems (AVCS), encompassed a broad range of products—including sensors, computers, and control systems—that would enhance driver perception and assist with driving tasks. Planners anticipated that different AVCS features and capabilities would be developed and deployed over different periods of time. Vehicle-based systems that give drivers warnings of impending dangers—such as products that provide blind-spot surveillance or improve night vision—were expected to be introduced first, followed by

³ ITS America is a nonprofit association established to plan, promote, and coordinate ITS in the United States. It comprises researchers, producers, and users of ITS products and services from academe, industry, and government. One of its chartered missions is to provide advice to the federal government on ITS.

systems that take control of certain driving tasks, such as braking in an emergency or adjusting vehicle speed according to the driver's desire for distance following other vehicles ("adaptive cruise control").

Over time, such systems would become integrated with intelligent traffic control and management infrastructure to "serve as fundamental building blocks for future systems" (ITS America 1992, III-34). For instance, electronic transmitters in the pavement might detect the position of vehicles within a lane, providing information to traffic control centers while sending information to motorists about traffic levels and roadway conditions and helping them stay in their lanes (Euler 1990). The evolution and integration of these technologies into a system that could provide full vehicle control was conceived as a possible long-range outcome of these developments, potentially providing a solution to future safety and highway capacity problems.

ALTERNATIVE VISION: FULLY AUTOMATED SYSTEMS EMERGING IN AN ACCELERATED, PLANNED MANNER

By the late 1980s, DOT had initiated several research projects on advanced vehicle and traffic control systems. The Federal Highway Administration (FHWA) was concentrating its ITS-related efforts on advanced traffic management techniques and control systems (FHWA 1992, 12–14); its sister agency, the National Highway Traffic Safety Administration (NHTSA), was beginning to test vehicle-based radar systems to maintain headways in semi-automated traffic. NHTSA's efforts included making small grants for research on these and other vehicle-based technologies that later would be grouped under the AVCS heading (TRB 1990, 145).

Following passage of ISTEA in 1991, however, DOT added a new element to its research program. ISTEA called upon DOT to "develop an automated highway and vehicle prototype from which future fully automated intelligent vehicle-highway systems can be developed" [ISTEA 1991, Part B, Section 6054(b)]. This legislative provision called into question the notion of a fully automated highway system emerging gradually through efforts to encourage incremental advances in intelligent vehicle and traffic control and information technologies. By mandating the prototyping of an automated vehicle and highway from which a future fully automated system could be developed, Congress implied that a fully automated system might indeed emerge in a deliberate and accelerated manner. This mandate represented a vision similar to that of GM researchers in the 1950s and 1970s who sought to specify an optimal fully automated highway system for application before the turn of the century (DOT 1980; DOT 1981).

The effect of this provision is evident in the ITS strategic plans of ITS America and DOT. Both presented dual visions of how fully automated

driving systems could emerge. ITS America's 1992 strategic plan, for instance, describes AVCS concepts that support automatic control as "long-term" while noting, "The goal is to have the first fully automated roadway or test track in operation by 1997" (ITS America 1992, I-12). Likewise, the 1992 DOT strategic plan calls for two distinctly different research paths on advanced vehicle and highway systems. One path, headed by NHTSA, would evaluate and investigate opportunities for implementing sensors, processors, and other technologies that could aid drivers in avoiding crashes. The focus would be on examining the need for, and the potential effects of, collision warning devices and other partially automated vehicle systems that could offer emergency control in near-collision situations (DOT 1992, 61-62). The second path, headed by FHWA, would develop and demonstrate a fully automated highway system that would serve as the basis for future developments (see Box 2-1). The evolutionary and accelerated research programs have coexisted within DOT during the past 5 years.

FEDERAL RESEARCH EFFORTS

DOT is not the only federal agency that supports work related to intelligent vehicles and highways. Within the U.S. government broadly, various efforts are under way to research and develop automation technologies that could have application to highway transportation. For example, as part of the robotics program of the U.S. Department of Defense, the Unmanned Ground Vehicles Program is working on relevant systems and technologies, such as obstacle detection, image processing, mapping, the Global Positioning System (GPS), and range finding. Likewise, various technologies and evaluation methods for automation controls, sensing systems, human factors, and other components and aspects of intelligent vehicle and highway systems are being investigated with federal funding by national laboratories (e.g., Sandia National Laboratory), the National Science Foundation, the National Institute for Standards and Technology, and the National Aeronautics and Space Administration. NHTSA and FHWA have tapped into the work of these other federal research and development programs.

NHTSA Research on Intelligent Vehicles

NHTSA's research on vehicle automation has been headed by its Crash Avoidance Office. The emphasis to date has been on establishing the knowledge and research tools needed to develop collision warning and driver assistance technologies (NHTSA 1997). Crash data are being examined to identify problems warranting attention, and preliminary human factors

**BOX 2-1: FHWA PLANS FOR FY 1993
HIGH-PRIORITY RESEARCH ON ADVANCED
VEHICLE CONTROL SYSTEMS (FHWA 1992, 28)**

The following quotation from FHWA describes the agency's initial plans for an automated highway system (AHS) research program.

In response to the Congressional mandate in the ISTEA to demonstrate a prototype automated highway system on a test track by 1997, the FHWA and the NHTSA have jointly developed a long-term program with the goal of generating a performance specification of an AHS, through extensive system development and testing. This performance specification will then be used by automotive product developers and transportation agencies to deploy AHS's late in the next decade. The 1997 demonstration is a major milestone in this overall program and will provide proof-of-concept feasibility of an AHS system. The AHS vision can be summarized as a system of instrumented vehicles and highways that provides fully automated (i.e., "hands-off") operation at better levels of performance (safety, efficiency, comfort) than today's highways and is financially affordable, where vehicles can operate in both urban and rural areas on highways that are both instrumented and noninstrumented. Acquisition planning for this major program is not final; however, two efforts are envisioned for fiscal year 1993: a broad agency announcement is planned to perform precursor system analyses relating to an AHS. Multiple parallel analyses are desired to provide the DOT and others in the IVHS community with a realistic range of AHS configurations and a better understanding of the issues dealing with AHS applications, technology, design, deployment, operation, and practicality; and a solicitation for a consortium to design and develop the prototype system for the 1997 demonstrations is planned. The consortium would use the results of the precursor systems analyses as a technical foundation in beginning prototype development. At a minimum, this consortium would consist of automobile manufacturers and transportation agencies, as these entities are key stakeholders in the future widespread deployment of AHS systems.

guidelines have been developed for the design of crash-warning devices and in-vehicle displays. NHTSA anticipates that the National Advanced Driving Simulator, scheduled for completion in 1999, will aid human factors research in this area (NHTSA 1997). To assess various crash-avoidance measures, including automated controls, NHTSA also is sponsoring work to develop a portable device that can be installed in test vehicles to monitor and record driver and vehicle information, such as vehicle speed and driver orientation.

NHTSA has formed partnerships with several automotive companies and suppliers to accelerate the development of collision-avoidance systems. NHTSA expects these partnerships to spur the commercial introduction of the safest and most effective of these systems.

FHWA and National Automated Highway System Research Program

Following passage of ISTEA, DOT established the National Automated Highway System Research Program, housed within FHWA. DOT initiated the program by sponsoring “precursor” studies aimed at identifying and understanding potential obstacles to the development and deployment of fully automated highway systems. These year-long studies (which are discussed in more detail in Chapter 4) were conducted by teams of researchers from universities, aerospace and automotive industries, and several defense, communications, and aerospace firms. Concurrent with these assessments, DOT sponsored separate human factors studies of automated highway systems—an area of inquiry specifically identified in ISTEA.

As the precursor studies were nearing completion—and no major obstacles to the development and deployment of a fully automated highway system were identified—DOT moved forward to the next phases of its research program: undertaking the congressionally mandated demonstration and selection of a preferred fully automated highway system. In doing so, DOT chose to concentrate funding on a national research consortium consisting of the kinds of organizations that were ultimately expected to design, build, deploy, and operate a fully automated highway system (DOT 1993, 3).

By involving such “stakeholders” at the outset, DOT hoped to expand program resources (funds, equipment, and skills) and prompt the automotive and highway industries to begin working cooperatively in this area and to agree on a fully automated highway system that would serve as the basis for future developments. Building such early support entailed many challenges that would require concerted public- and private-sector effort. Consortium members would be expected to contribute 20 percent of the funds for the research program effort, which would “provide the basis for, and transition to, the next major performance upgrade of the U.S. highway system through the

use of automated highway technology” (DOT 1993, 4). After a competitive process, a team headed by GM was selected in late 1994 to form the National Automated Highway System Consortium (NAHSC). (The organization, procedures, and accomplishments of NAHSC are briefly reviewed here for background purposes; they are described in more detail in Chapter 4.)

NAHSC comprised nine contributing organizations, known as core members. In addition to GM, the core membership consisted of Bechtel Corporation, the California Department of Transportation (Caltrans), Carnegie Mellon University, Delco Electronics Company, Hughes Electronics Corporation, Lockheed Martin Corporation, Parsons Brinckerhoff, Inc., and the University of California at Berkeley. These core members had expertise in areas ranging from electronics and vehicle manufacturing to highway construction and operations, all of which were considered central to the eventual development and deployment of fully automated highway systems. DOT also served as a member of the consortium and was responsible for representing the interests and perspectives of transportation users.

NAHSC was given several milestones to reach in achieving the goal of identifying a preferred fully automated highway system. It focused its early efforts on achieving three milestones: gaining an understanding of the basic requirements of an automated highway system from the perspective of transportation users, providers, and other “stakeholders”; characterizing the general concepts, or kinds of systems, that are candidates for achieving these requirements; and undertaking a public demonstration of automated highway system technologies, as mandated by Congress. To pursue the first of these goals, the consortium sponsored several workshops and outreach activities for transportation users, automobile makers and their suppliers, the highway community, and other interest groups. An associates program was established to bring in the views and expertise of individuals and organizations from outside the core membership.

Work on the second milestone led to the identification of several potential configurations for a fully automated highway system, grouped into “concept” families. According to one concept, for example, vehicles would operate automatically through independent means using on-board computers and sensors; according to another, vehicles would operate in synchronized platoons governed by a combination of vehicle- and infrastructure-based sensors, computers, and communications systems. In the NAHSC work plan, each concept was to be evaluated with regard to technical feasibility and safety, traffic throughput, and infrastructure cost impacts, as well as societal, institutional (e.g., jurisdictional or legal), and environmental implications. Those concepts showing the greatest promise would be evaluated further, leading to the eventual identification of a system configuration most suitable for prototype development and testing.

A public demonstration of several automation technologies was held in San Diego, California, in August 1997, fulfilling the mandate in ISTEA.

Next Steps in DOT's Program

The 1997 demonstration originally was planned as the precursor to achieving the next major step in the consortium's work plan: specifying a preferred automated highway system for prototype development, testing, and demonstration. This follow-on phase coincided, however, with the scheduled reauthorization of surface transportation legislation—a time when DOT budget and program priorities are scrutinized by the administration and Congress. Having complied with the congressional mandate for a 1997 demonstration, DOT turned its attention to the future of NAHSC.

Before the San Diego demonstration, DOT had indicated that the consortium's mission was not well suited to more immediate program goals. The administration's surface transportation bill (NEXTEA), submitted to Congress in the spring of 1997, included no explicit provisions prolonging NAHSC funding. Concurrently, DOT notified the consortium of preliminary plans to de-emphasize specification of a fully automated highway system and to give greater attention to the development of nearer-term intelligent vehicle technologies with the potential to attain early safety benefits.

According to a DOT draft, the new Intelligent Vehicle Initiative (IVI) program would focus on the development of systems that warn drivers of unsafe situations, recommend evasive actions, and take temporary control of driving during hazardous or near-collision situations (DOT 1997). Essentially, IVI would expand the intelligent vehicle research program already under way within NHTSA. In its early draft, DOT outlined plans to collaborate with industry to develop and evaluate intelligent vehicle technologies that show the potential to be deployed over the next decade. This collaboration would focus primarily on the automotive industry because most nearer-term driver assistance and partial-control products are expected to be vehicle-based. Automobile makers and their suppliers, for example, would be encouraged to equip a small number of cars with collision warning systems, adaptive cruise controls, and blind-spot surveillance systems (DOT 1997, 1). Industry was expected to work with DOT and other research organizations to evaluate and improve the performance of these technologies and find ways to integrate them into safe and effective crash-avoidance systems that could be offered to consumers (DOT 1997, 9). The goal of the IVI program would be "to accelerate the development, introduction, and commercialization of driver assistance products to reduce motor vehicle crashes and incidents" (DOT 1997). In effect, DOT moved toward the vision of individual ITS products leading to the eventual emergence of automated systems, thereby casting into doubt the future of the NAHSC program.

The next major milestone in the consortium's original agenda was to select a preferred automated highway system configuration, leading to the development of a final system for prototype design and testing by 2002. When presented with DOT's new plans, NAHSC sought to modify its work plan to better align it with the new emphasis. Doing so proved difficult, however, in light of the consortium's original mission, structure, and decision-making and management processes.

The issue became moot in December 1997, when DOT—citing changed priorities and budgetary constraints caused by the temporary extension of ISTEA—informed NAHSC of its decision to reduce funding for the program, withdrawing all financial support as of September 30, 1998.

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ABBREVIATIONS

DOT	U.S. Department of Transportation
FHWA	Federal Highway Administration
NAHSC	National Automated Highway System Consortium
NHTSA	National Highway Traffic Safety Administration
TRB	Transportation Research Board

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3

NEEDS, CONCEPTS, AND ISSUES

Reviewed in this chapter are the nation's major highway safety and capacity needs that underlie efforts to develop and deploy fully automated highway systems. A general description of several automation concepts, ranging from partially to fully automated systems, follows. The chapter concludes with a brief discussion of some of the safety, institutional, environmental, and other public policy issues that arise in considerations of the prospects for deploying fully automated highway systems. Specification of a fully automated highway system will require understanding and balancing of these issues.

HIGHWAY SAFETY AND CAPACITY NEEDS

The need to reduce the incidence and severity of highway crashes, especially the large share caused by driver error, offers a compelling reason for investigating automated and other intelligent vehicle and highway technologies. Another is the need to accommodate escalating traffic on urban commuter routes and intercity passenger and freight corridors. Indeed, meeting these related needs through integration and improvements in motor vehicle and highway technologies is the central goal of the large federal research and development effort under way in intelligent transportation systems (ITS) generally (ITS America 1992, 1-1 to 1-2).

Safety

Impressive gains have been made in motor vehicle safety in the United States during the past three decades. In 1970, about 45,000 people were killed on the nation's roadways (excluding pedestrians). About 20 percent fewer fatalities were reported in 1996, although the number of miles traveled by

the vehicle fleet rose more than 75 percent during that period (NHTSA 1996, Table 2; NHTSA 1997a, 23–28).

Among the reasons for this dramatic improvement are the introduction and use of occupant protection devices and features in motor vehicles, improved highway designs, and changes in certain driver behaviors (such as drunk driving). The highway and motor vehicle industries, the federal government, and state and local transportation and law enforcement agencies have all contributed to this progress, as have changes in public perceptions and expectations regarding motor vehicle safety and acceptable driving behaviors.

These gains notwithstanding, motor vehicle crashes remain a leading cause of accidental death and disabling injuries in the United States, especially among young people. The federal government estimates that in addition to lives lost and injuries suffered in the most serious crashes, traffic accidents of all kinds burden society with more than \$150 billion in economic losses from property damage, traffic delays, lost worker productivity, fuel use, and other direct and indirect effects (NHTSA 1996). Although the current traffic fatality rate of 1 per 100 million km (1.7 per 100 million mi) is a historic low—and among the lowest in the world—further efforts to increase highway safety are warranted.

The factors contributing to highway crashes, especially those resulting in death and severe injuries, have been the subject of considerable research—as well as public programs and policies designed to address them. Automobile manufacturers and their suppliers have spent many years and billions of dollars researching, developing, and deploying motor vehicle safety improvements. State and local governments have sought to improve the safety of the roads on which these vehicles travel, including the performance of drivers. Within the federal government, the National Highway Traffic Safety Administration (NHTSA) and the Federal Highway Administration (FHWA) have the main responsibility for ensuring motor vehicle, highway, and driver safety.

One way that researchers frame the highway safety problem is to separate motor vehicle crashes into their pre- and post-crash phases. “Crash avoidance” is the term often used to describe improvements in vehicles, highway environments, and driver performance that can reduce the probability that a crash will occur. “Crash protection” and “crashworthiness” are terms that refer to improvements in vehicles and the highway environment that can reduce the severity of crashes—for instance, by protecting the vehicle’s occupants and reducing the impact forces of the collision.

Enhancements in crashworthiness and other measures to protect vehicle occupants in crashes have been the subject of highway and motor vehicle safety programs. FHWA and state and local highway agencies have sought to reduce crash severity by providing a more forgiving road environment—for

example, through deflective guide rails, breakaway supports for lights and signs, crash cushions, wider medians, and tree-clear zones beside freeways. FHWA has fostered these improvements through its own research programs and by working with state and local authorities to encourage and mandate the use of safer roadway designs and equipment.

Likewise, motor vehicles have become more protective of occupants as a result of many changes in vehicle design, materials, and safety features. All new passenger cars, for instance, have energy-absorbing frames and bodies, seat belts, padded steering wheels, and air bag restraint systems. NHTSA has sought to increase vehicle crashworthiness through performance standards that encourage industry to develop safer vehicle designs and features. It also has promoted vehicle safety through other means. During the 1970s, for instance, the agency worked with domestic and foreign automobile manufacturers to establish an Experimental Vehicles Safety Research Program (later renamed the Research Safety Vehicle Program), through which occupant-protection concepts such as air bags, automatic seat belts, and other occupant restraints were demonstrated to industry and the public (TRB 1991, 146–147).

Improvements in crash avoidance have proved far more difficult to attain, largely because the probability of a crash is affected by an array of complex and interacting factors involving the drivers, vehicles, and the highway environment. The human factor—the driver—is particularly important. Driver error and poor performance, caused by factors ranging from momentary distractions to alcohol impairment, are the main contributory causes of most highway crashes. To compensate for or enhance driver performance, NHTSA and automobile manufacturers have focused much of their attention on designing vehicles that are easier to use and more responsive to drivers—for instance, through better braking, steering, stability, and visibility. Antilock braking systems, rear window defoggers, brighter head lamps, and high, center-mounted brake lights are examples of vehicle equipment designed to aid drivers in routine and hazardous situations. In addition, many improvements have been made in roadway designs, materials, and equipment to facilitate safe driving: flatter grades, left-turn lanes, pavements that drain well and are skid-resistant, rumble strips on shoulders (to alert drowsy drivers), and reflective signs and edge markings. To influence driver behavior directly, governments at all jurisdictional levels have sought to discourage certain hazardous driving habits, such as speeding and driving when drunk or fatigued.

Despite the many crash avoidance measures that have been undertaken, driver error remains the most important cause of motor vehicle crashes. In the belief that there is a large untapped potential for reducing motor vehicle crashes by improving driving performance, NHTSA has been developing new research tools to understand driving behavior, such as an advanced driving

simulator. It also has evaluated crash data to better understand collision problem areas and their causal factors. Working with motor vehicle manufacturers and suppliers, NHTSA has begun operational tests to examine the potential for advanced vehicle systems that could detect impending crashes, alert drivers, and take temporary control of a vehicle if warranted (for instance, by applying the brakes in an emergency) (NHTSA 1997b, 1).

Full automation of highways and vehicles—that is, automation of routine driving tasks—has received comparatively little attention within NHTSA and the motor vehicle safety community generally. This lack of attention derives in part from the tendency for fully automated highways to be viewed as remedies mainly for congestion on urban freeways and main commuter routes (NHTSA 1997b, 3). Highway crashes occur throughout the vast public road system, and rural routes—seldom considered early candidates for full automation—are the location of a disproportionately high share of fatal crashes. Although nearly 15 percent of the nation's motor vehicle travel occurs on urban Interstate highways, they account for only 5 percent of fatal crashes (FHWA 1996, Table VM-2; NHTSA 1996, 1997a). Full automation of these urban freeways therefore is viewed as having a relatively limited impact on the overall highway safety problem in the United States. If fully automated systems could be applied to a wider assortment of driving environments—or divert significant amounts of traffic from less-safe roads—interest in them within the highway safety community could be expected to grow.

Highway System Capacity

During the past half century, the United States has experienced extraordinary growth in motor vehicle travel. Since 1950—a period in which the U.S. population rose by 75 percent—vehicle miles traveled nationally have grown nearly fivefold, doubling about every 20 years (TRB 1997, 40). In the past two decades alone, motor vehicle travel has grown more than two-thirds. Although much of this growth in driving has occurred on urban commuter routes, significant increases in travel have occurred on nearly all segments of the system, for all kinds of vehicles. DOT expects motor vehicle travel to grow another 35 to 50 percent over the next two decades (DOT 1995, 162–168). In the meantime (if recent history is an indication), the capacity of the nation's highway system will continue to grow—but at a pace slower than the growth in travel. Growing congestion is a likely outcome on many highways in fast-growing metropolitan areas.

Escalating motor vehicle travel has been caused by and has contributed to several important social and demographic trends, such as the maturing of the large baby boom population and the influx of women into the workforce and

driver pool beginning in the mid-1960s. A decade earlier, the United States had embarked on the Interstate Highway System, a public works program that has added more than 72 000 km (45,000 mi) of modern freeways across the country. During this period, the country has become increasingly urbanized as metropolitan areas have grown in number and population. Metropolitan areas also are spreading out; nearly 20 percent of the land in the contiguous United States is located in areas defined by the Bureau of the Census as having urban population densities. By comparison, only 7 percent of the U.S. land area was classified as urban in 1950 (Bureau of the Census 1995, Table 40).

As metropolitan areas have proliferated and expanded, driving patterns have changed. In many metropolitan areas, the central city no longer accounts for the dominant share of the population or the largest number of jobs, shops, and other destinations. Traditional radial road and transit commuter corridors that carry residents and workers between suburban and downtown areas have become insufficient in many places as travel origins and destinations have become increasingly dispersed, varied, and distant. As a result, state and local transportation agencies have had to add capacity across their entire networks by building new roads such as beltways and by-passes and by widening and upgrading many existing routes that once served only local traffic. In the past decade alone, the amount of lane-mileage on the nation's urban arterials and collector roads has grown 20 percent (FHWA 1986, 1996, Table HM-60).

Road building, however, is expensive, time-consuming, and often controversial because of concern about traffic and environmental impacts, historic preservation, and protecting the character of communities. From 1990 to 1994, the average cost of constructing one mile of new federal-aid highway (consisting of primary and major secondary routes) was \$1.75 million per km (\$2.8 million per mi) (FHWA 1994, IV-36 and IV-37), not including the purchase of expensive rights-of-way. Road widening and other improvement projects averaged more than \$600,000 per km (\$1 million per mi). For most large urban areas, where the reconfiguration of a single interchange on a major freeway can cost tens of millions of dollars and cause substantial traffic disruptions, these figures would run much higher.

Faced with high costs and other difficulties associated with adding new travel lanes—including the need to control air pollution—many state and local governments are seeking ways to accommodate burgeoning traffic without creating more physical infrastructure. Many areas are trying to extract more capacity from their existing road networks through ramp metering, synchronized traffic lights, reversible lanes, travel on shoulders, better incident management, and other modifications to traffic operations. Some localities are trying to reduce travel demand by promoting transit, ridesharing, and more flexible work and commuting schedules. These efforts may have

enabled some jurisdictions to defer large road-building projects or avoid more stringent actions to curb driving demand.

Interest in new ways to increase road capacity and influence demand for motor vehicle travel has sharpened as traffic congestion has worsened and continued to spread. Exactly how motor vehicle travel patterns and trends will unfold over the next several decades remains unclear. Some areas of the United States that today have excess highway capacity and few congestion problems may become more appealing to businesses and residents over time, providing a possible check on chronic and worsening gridlock in already congested urban areas. According to emerging demographic trends, a slowdown in the rate of growth in motor vehicle travel is likely during the second quarter of the next century, when a plateau may occur in the travel-intensive middle-aged population, now composed of baby boomers (TRB 1997, 56–61).

Even a somewhat slower rate of growth in motor vehicle travel, however, will continue to produce higher traffic volumes. About one-quarter of urban Interstates now carry more than 100,000 vehicles per day, and many carry much higher volumes. This figure represents a 15 percent increase over 1985 volumes, although the physical capacity (lane-mileage) of urban Interstates has barely changed during the period (FHWA 1986, 1996, Table HM-37). Traffic volumes would be even higher in many cases, except that highways have reached their capacity. Indeed, traffic volumes on more than 45 percent of urban Interstates are now above design capacity (the point where throughput and travel efficiency are maximized), compared with 35 percent in 1985 (FHWA 1986, 1996, Table HM-61).

Another cause for the sustained and rapid pace of growth in motor vehicle travel has been the growth in intercity travel by commercial trucks. Travel by tractor-trailers and other combination trucks has nearly tripled since 1970—making trucking by far the fastest-growing component of motor vehicle travel (FHWA 1970, 1996, Table VM-1). Not only has the Interstate Highway System become the primary means of personal travel for short- to medium-distance trips, it also has become the predominant means of transport for many kinds of freight. Combination trucks account for only about 6 percent of total vehicle miles traveled, but they are prevalent on Interstate highways (FHWA 1996, Table VM-1). On rural Interstates, which serve as main trunk corridors for intercity truck travel, combination trucks account for more than 15 percent of vehicular traffic (FHWA 1996, Table VM-1). Further growth in truck travel is expected, raising concerns about the ability of some heavily traveled intercity corridors to continue accommodating both freight and passenger vehicles safely and efficiently.

Confronted with the strong probability of continued growth in motor vehicle travel and the reality of an aging and slow-growing road network,

some state and local governments are counting on ITS to improve traffic operations and overall system efficiency and capacity.

Intelligent transportation systems already are being deployed and tested throughout the United States. For instance, systems that collect and transmit real-time information on traffic conditions for travelers and transportation agencies—enabling the former to modify their travel plans and the latter to clear incidents and reroute traffic efficiently—already are in place. Transit authorities and trucking companies are using automated tracking and dispatch systems to dynamically route and reroute vehicles in response to information on traffic patterns and congestion. Navigation systems with enhanced pathfinding, or route guidance, are being used in selected areas and in test markets to give travelers more information on congestion and alternative routes. Electronic toll and traffic management systems that scan or communicate with vehicles to collect tolls automatically—such as the E-Z Pass system in the Northeast—are being deployed widely to reduce delays at toll plazas. Such systems eventually may be employed for variable toll pricing and other forms of travel demand management.

These and other ITS technologies and products have been grouped by the ITS community into five functional areas: advanced traffic management systems, advanced traveler information systems, commercial vehicle operations, advanced public transportation systems, and advanced vehicle control systems. As the technologies and systems in all of these functional areas are developed and integrated over time, they hold the potential to continually improve traffic operations and highway capacity. Indeed, over the longer term, ITS promises increasingly interconnected and compatible components that merge to form an “intelligent infrastructure.”

A main promise of fully automated highway systems is dramatic gains in highway throughput. The ITS America strategic plan, for example, anticipates doubled or tripled traffic throughput in corridors supported by fully functioning ITS that include vehicle automation (ITS America 1992, I-12).

FEATURES AND CONCEPTS

ITS encompasses several advanced driving features and concepts, ranging from obstacle detection and warning systems that are possible precursors of partially automated driving systems to fully automated vehicles traveling on instrumented highways. Some automation features already are in use or in advanced stages of development, whereas others remain conceptual. Computer-aided antilock braking systems, an automated feature, have been in widespread use for several years. Collision warning devices, such as blind-spot detectors, have found niche applications in some commercial fleets.

Adaptive cruise control systems, which include radar braking, may be introduced abroad within the next few years.¹

The following section presents an overview of several intelligent and automated vehicle features and systems. Some are concepts; others are being developed and, in some cases, offered commercially. The study committee has not examined their technical feasibility or prospects for implementation. The main purpose of the discussion—drawn from descriptions provided by NHTSA and the National Automated Highway System Consortium (NHTSA 1997b; NAHSC 1997)—is to indicate the variety of advanced features and systems that are being explored.

Partially Automated Systems and Their Precursors

Concepts for partially automated driving fall into three groups: technologies that give drivers information, notifications, and warnings; those that take limited control of the vehicle in emergency situations; and those that automate certain routine aspects of driving but rely on manual control for most driving functions. Systems that make up the first group, some of which are being offered for sale in the United States and abroad, sometimes are viewed as precursors to systems in the second and third groups. In each case, various technological options are available, from sensors on-board the vehicle (e.g., radar) to radio communications between vehicles in traffic and between vehicles and the roadway infrastructure.

Notification and Warning Systems

These systems—some of which already are operational—would alert the driver to a threatening condition, allowing him or her to respond as appropriate. Advanced versions might give advice on suitable response options—for instance, suggesting braking or steering actions. The driver would be fully responsible for vehicle controls and could deactivate the warning system as desired.

Several emergency warning features are conceivable; some are now being offered commercially. A frontal warning feature, for instance, could detect when a vehicle is too close to the one immediately ahead, warning

¹ When the term “automation” applies is a matter of debate because different advanced features offer not only different degrees of automation but different kinds. For instance, collision warning systems may not automate vehicle controls but they do automate driver information acquisition. No attempt is made here to precisely define automation. This may result in some imprecision in the discussion, which the committee accepts for the general purposes of this report.

the driver when the distance equals a predefined limit for the travel speed. The system would judge the rate at which the distance in front is decreasing and give increasingly urgent warnings about the possibility of collision. A side-looking or blind-spot warning feature, employing sensors on the side of the vehicle, could detect the presence of a vehicle in the adjacent lane. If the driver were to indicate a desire to change lanes—for instance, by using a turn signal—an audio or visual alert would be given. A lane-departure warning feature, which would use sensors to detect the position of the equipped vehicle in relation to lane markings or the roadway shoulder, would warn the driver as the vehicle approached or exceeded the lane boundaries. Warnings could increase in intensity as the vehicle drifted closer to the lane edge.

Other warning systems might serve as precautions. For example, a curve approach warning system might alert a driver of a difficult curve ahead, sending notification if the vehicle is approaching the curve at excessive speed. Roadway geometric information of this sort might be obtained from roadside communications beacons. Similarly, surface-condition warning systems might detect when tire-road friction, and therefore skid resistance, is reduced because of water, ice, or other road surface conditions. As road surface conditions worsen, increasingly strident warnings could be provided.

Other systems might detect and notify the driver of incidents, obstacles, or stopped vehicles in the roadway—perhaps communicated from a traffic management center, roadside traffic monitoring devices, or other vehicles in preceding traffic. On-board monitoring systems might detect driver drowsiness or degradation in the vehicle's safety-related systems and components, such as a loss in tire tread or pressure.

Temporary Emergency Controls

The foregoing warning and information systems might be expanded and modified to include emergency control features that would be activated when the driver fails to respond to a warning or when the time to respond is limited. These controls would help drivers avoid crashes or lessen their severity by enabling drivers to take evasive action. For instance, a frontal collision avoidance feature might detect when the distance between vehicles had closed to the point where a collision would result unless brakes were applied; if the driver failed to respond, the system could apply the brakes. Likewise, side-collision and lane-departure avoidance systems that exert emergency control might evolve from first-generation warning systems.

Partially automated controls also might be designed to prevent common kinds of driving mishaps. For example, a vehicle approaching a curve at an excessive speed could trigger the vehicle's accelerator to provide significantly

greater than normal resistance, encouraging a reduction in vehicle speed. If a crash were imminent, the system could slow the vehicle as it approached the curve.

Continuous Partial Controls

In contrast to warning systems and emergency controls, partial automation applications might offer drivers continuous assistance with certain routine or repetitive driving tasks. With these systems, the driver would retain control of the vehicle generally but relinquish primary control of some driving tasks. The driver also would have the ability to revert to manual control as necessary.

Adaptive cruise control systems currently are being developed by some automobile manufacturers and their suppliers. Conventional cruise control systems—normally used during freeway driving—simply maintain vehicle speed at a level set by the driver; only the driver can change the speed from the preset level. Advanced cruise control systems would employ forward-looking sensors so the vehicle would be capable of adjusting speed to maintain a safe following distance from the vehicle in front. The vehicle would follow at a speed and within a headway parameter set by the driver, slowing when necessary to maintain a safe headway.

Another routine driving task that might lend itself to automation assistance is lane-keeping. Sensors on the vehicle would determine the position of the vehicle relative to lane boundaries, roadway shoulders, or special instrumentation installed in the roadway (e.g., magnetic markers). Using these cues, the lane-keeping system would keep the vehicle in the center of its lane by controlling steering and making other adjustments.

Lane-keeping systems used in combination with advanced cruise control would significantly reduce the role of the driver; these systems generally are regarded as crossing the threshold into fully automated operations.

Fully Automated Highway System Concepts

Fully automated driving often is described as “hands-off, feet-off driving” because the driver is fully disengaged from all, or virtually all, driving tasks. Presumably, some partial-automation features, such as obstacle detection, could be employed when fully automated operations are not engaged.

NAHSC grouped full-automation concepts according to several key attributes, particularly the degree to which vehicles and infrastructure work together to enable full automation. The following scenarios illustrate how

fully automated driving could be achieved in alternative ways that rely to varying degrees on vehicle and infrastructure cooperation.

Independent Vehicles Operating Automatically

The first scenario assumes that fully automated vehicles operate along with manually driven vehicles, often traveling in the same lanes. Fully automated vehicles would employ sensors (e.g., optical and radar), computers, and other onboard systems. Neither infrastructure assistance nor communication with other vehicles would be required. Deployment therefore would depend on when such vehicle-based technologies are affordable, effective, and safe. Fully automated operations might ensue through gradual implementation and integration of partial automation systems, such as lane-keeping and collision avoidance systems. Construction or conversion of lanes dedicated to fully automated traffic would not be necessary. Because of mixed traffic and lack of coordination among vehicles, tight spacing of vehicles and increased speeds probably would not be possible—reducing the potential for significant gains in traffic throughput. Mixing of fully automated and non-automated traffic also would raise many concerns about human factors and traffic safety and management.

Cooperating Fully Automated Vehicles

In the second scenario, vehicles equipped with onboard sensors and computers would share information with other vehicles to coordinate maneuvers and enable fully automated travel. Fully automated vehicles would have sufficient sensing, computing, and communications capabilities to work cooperatively in achieving close headways, detecting and avoiding obstacles, and coordinating responses to contingencies as they unfold in traffic. Though some infrastructure support, such as radio repeaters and controllers to relay and boost signals, might be needed to aid communications, vehicle-to-vehicle interaction would be the primary means of automatic control. Dedicated travel lanes might or might not be required; only where non-automated traffic were excluded, however, would highly orchestrated and efficient traffic flows be likely (e.g., by coordinating lane changes, merging, and hazard warnings) to permit large gains in throughput.

Infrastructure-Supported or Assisted Fully Automated Driving

The third scenario envisions fully automated vehicles operating on dedicated lanes, using infrastructure instrumentation, intelligence, or both to enhance

operations. The roadway would have an important, possibly active, role in the control of vehicle movements and overall traffic flows. Fully automated lanes would be physically separated from manual traffic by fencing, barriers, or medians, which also would exclude debris, animals, and other obstacles. Using dedicated lanes would reduce the potential for outside interference and allow faster vehicle speeds and closer spacings to increase throughput substantially, with traffic moving in coordinated platoons of fully automated vehicles. With such infrastructure support—and the economies of scale realized in providing it—the need for more expensive vehicle-based technologies could be reduced. The construction of new lanes might be required, however, or existing lanes would need to be converted for use by fully automated traffic.

Each of these generic concepts raises issues with respect to safety, traffic operations, and the environment, as well as other technical and practical considerations.

ISSUES ASSOCIATED WITH FULLY AUTOMATED DRIVING

Full automation concepts not only differ from one another in their technical feasibility, they also are likely to have different impacts on highway safety and capacity, as well as their own sets of environmental, financial, and societal implications. For example, fully automated vehicles operating in platoons on protected and dedicated travel lanes (as in the third scenario) could lead to large gains in traffic throughput because vehicles could be closely spaced and driven at high speed. To achieve this added throughput, however, significant investments might be needed in building or converting lanes to handle fully automated traffic. Such investments might prove financially and politically difficult for many jurisdictions. On the other hand, fully automated vehicles operating autonomously (that is, without dedicated lanes, as in the first scenario) might require minimal public-sector investment in new infrastructure but would be more expensive to motorists.

These kinds of trade-offs would require careful examination and balancing before a preferred fully automated highway system could be specified. Such consideration, however, requires a thorough understanding of the impacts and trade-offs and the ability to weigh and value them from a societal standpoint. The safety effects of alternative concepts, for instance, would need to be assessed and weighed against their respective traffic throughput and environmental impacts; public-sector versus private-sector investment requirements would need to be considered and balanced; and so forth. Judgments such as these often are made in the marketplace or through political and public policy processes.

As Box 3-1 shows, the specification of a fully automated highway system raises complex safety, environmental, and institutional issues. These and other issues have been the subject of investigation by DOT and the NAHSC program. Perhaps the most difficult aspect of specifying a fully automated highway system is gaining consensus on these issues and their relative importance.

BOX 3-1: DESIGN AND IMPLEMENTATION ISSUES FOR FULL AUTOMATION

System Safety and Public Acceptance

To ensure user acceptance, a fully automated highway system must be designed and implemented with many complex human factors and operational reliability considerations in mind. For instance, decisions about which vehicle controls are automated and how these systems interface with the driver will affect system safety. The extent to which motorists would accept reduced manual control of their vehicles or be willing to travel in automated vehicles at close following distances, on narrower lanes, and at higher speeds is unclear. The potential for multiple-vehicle crashes, with catastrophic consequences, may require safety design and management methods analogous to those required for air travel.

Overall Effects on Environment and Traffic

A change in the surface transportation system as significant as that envisioned for fully automated highways would have many ramifications; for example, it might affect where people live, commute, and socialize, as well as energy use and emissions. A faster, more efficient highway system might enable commuters to live farther from city centers—leading to increased land development and urban encroachment into rural and wilderness areas. Increases in total travel might cause aggregate fuel use and emissions to rise even if automated driving proves to be more energy-efficient. The effects of increased traffic capacity and volumes on automated highways would have implications for traffic levels throughout the system. Automated roads might divert traffic from nonautomated roads; they also could increase traffic on surface streets near exit and entrance points.

BOX 3-1 (continued)*Political and Institutional Issues*

Many practical issues arise in considering the role of state and local governments in building and operating automated highways. For instance, can state and local transportation agencies—burdened with maintaining existing networks of aging highways—be expected to build, maintain, and operate a much more sophisticated system of automated highways? Likewise, is it reasonable to expect state and local jurisdictions to work together effectively in planning and operating automated highways? If many motorists cannot afford automated vehicles, will it be politically feasible to dedicate lanes to automated traffic?

Liability Concerns

Tort liability will affect the kinds of automated systems developed and deployed. Most automobile liability cases today involve motorists (or their insurance companies) suing one another over crashes; this situation exists because most crashes are caused by driver error, not equipment failures or flaws. The introduction of automated controls in vehicles and highways could fundamentally alter tort liability because the design, construction, and operation of automated systems would have a more direct impact on motor vehicle safety. The significance of the liability concern presumably would depend on, and influence, the kinds of automation systems that emerge.

REFERENCES

ABBREVIATIONS

DOT	U.S. Department of Transportation
FHWA	Federal Highway Administration
NAHSC	National Automated Highway System Consortium
NHTSA	National Highway Traffic Safety Administration
TRB	Transportation Research Board

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4

NATIONAL AUTOMATED HIGHWAY SYSTEM RESEARCH PROGRAM

The key developments leading up to the creation of the National Automated Highway System Consortium (NAHSC), as well as its organization and its major accomplishments since its inception in late 1994, are discussed in this chapter. This review covers the steps taken by the U.S. Department of Transportation (DOT) to implement the National Automated Highway System Research Program—including the decision to concentrate this research in a consortium of government, industry, and academic organizations—and the mission, procedures, and achievements of NAHSC.

EARLY DECISIONS AND ASSESSMENTS

The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) called on the Secretary of Transportation to develop an automated highway and vehicle prototype from which future fully automated systems could be developed (see Chapter 1 for the specific wording of this section of the Act). In doing so, ISTEA called upon DOT to investigate human factors issues pertaining to fully automated vehicles and highways, have a fully automated roadway or test track in operation by 1997, and develop a system that could accommodate the installation of automation equipment on new and existing vehicles. Beyond these stipulations, the legislation did not give DOT direction on how the research and demonstration activities should be undertaken or what was meant by the term “fully automated highway systems.”

Program Initiation

Given latitude to determine the best means of fulfilling the legislative mandate, DOT elected to make the National Automated Highway System Research Program the longest-range component of its Intelligent Transporta-

tion Systems (ITS) program. DOT chose to go beyond the 1997 demonstration required by Congress by establishing a program that would (by the year 2002) specify, develop, and demonstrate a prototype fully automated highway system on which future systems would be based.

Among the first steps taken by DOT in establishing the research program was to identify several essential features of a fully automated highway system that could be used by researchers to begin examining these systems. The characteristics listed in Box 4-1 were identified as guiding assumptions for investigating fully automated highway systems.

Some of these system requirements—for instance, that existing vehicles have the capability to be retrofitted for fully automated driving—were developed in response to stipulations in ISTEA. Most, however, stemmed from DOT's own determinations about the characteristics that would make fully automated driving technically and commercially viable. These system requirements were used in work sponsored by DOT to develop more than a dozen alternative configurations of fully automated highway systems. These "representative system configurations" (RSCs) differed mainly in their physical and technical approaches to full automation—for instance, whether ded-

BOX 4-1: ESSENTIAL FEATURES OF AN AUTOMATED HIGHWAY SYSTEM (FHWA 1996, 11–12)

- ◆ All vehicle types (automobiles, buses, trucks) will be supported in a mature system, although initial deployment would be on automobiles.
- ◆ Automated vehicles will be instrumented, enabling them to operate automatically on instrumented segments of the roadway.
- ◆ Not all vehicles and roadways will be instrumented—instrumented vehicles will be able to operate on noninstrumented roadways, only instrumented vehicles will be allowed to operate on instrumented roadways, and noninstrumented vehicles will be instrumented on a retrofit basis.
- ◆ Automated operations will occur on freeway-type roads and will work in a wide range of weather conditions.
- ◆ Automated highways will perform better than today's roads and vehicles in terms of safety, throughput, user comfort, and environmental impact.
- ◆ The system will be practical, affordable, desirable, and user-friendly.
- ◆ The system will rely primarily on noncontact, electronics-based technology as opposed to mechanical or physical contact techniques—though the latter might be part of a backup subsystem.

icated lanes would serve fully automated traffic, where transition lanes would be located, whether vehicles and roadways would communicate with one another, and how much roadways would be instrumented to control vehicle speed, maneuvering, and spacing. Although the RSCs were not developed with reference to a specific application, it was generally assumed that they would permit fully automated driving on Interstate highways and other high-volume freeways.

Analysis Phase

Having identified these alternative configurations for fully automated systems, DOT embarked on the analysis phase of its research program. DOT planned three phases for the program (see Figure 4-1). The first two have been undertaken. The third, including operational tests of a fully automated highway system, was scheduled to begin in 2001.

The first phase, the analysis phase, consisted of several “precursor” studies conducted by teams of researchers and practitioners from government, industry, and academe over the course of 1 year. The precursor studies, undertaken during 1993 and 1994, covered various topics. The study teams conducted their work by several means, including workshops, computer

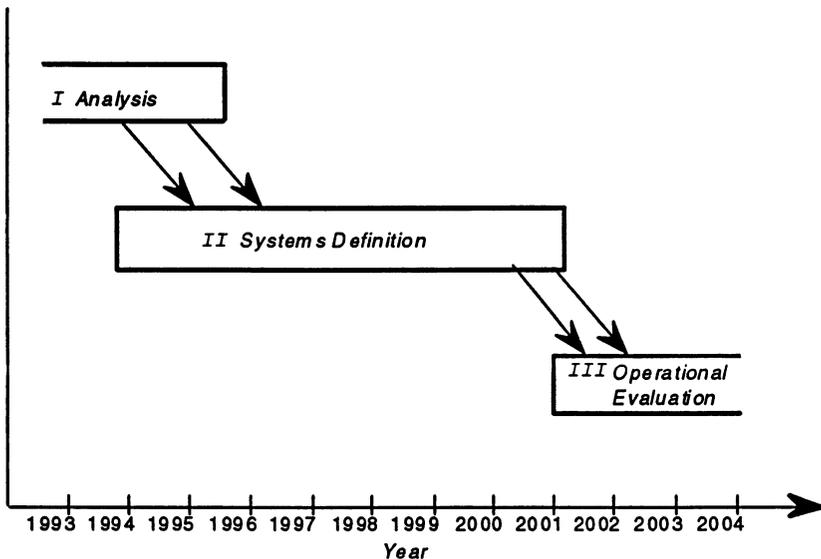


FIGURE 4-1 Planned phases of National Automated Highway System Research Program.

simulations, literature reviews, and multidisciplinary brainstorming sessions. The main purpose of these studies was to provide an early assessment of important issues and problems that might arise in developing and implementing fully automated highway system concepts (see Box 4-2 for examples of key findings). The precursor study teams therefore focused their efforts on identifying major technical, environmental, and safety impacts from implementation of a fully automated highway system. On the basis of these assessments, none of the precursor studies found reason to question the aim of the follow-on “systems definition” phase of the National Automated Highway System Research Program, which would aim to specify, develop, and test a fully automated highway system.

BOX 4-2: KEY FINDINGS FROM PRECURSOR STUDIES (FHWA 1996)

Urban and Rural Settings [Battelle, Calspan, Delco, Partnership for Advanced Transit and Highways (PATH)]

- ◆ Urban travelers, particularly commuters to and from work, are potential early candidates for automated highway system applications. They are more likely to be willing to pay the added cost of vehicle instrumentation. High Occupancy Vehicle and transit users are the earliest candidates among urban travelers.
- ◆ Building new roads and adding rights-of-way will be problematic in urban areas. Using existing lanes for automated traffic may be necessary.
- ◆ Major urban design challenges will involve entry and exit lanes and controls for mixing of automated and nonautomated traffic.
- ◆ The system will need to support mixed automated and nonautomated traffic in rural areas.
- ◆ Alternative system configurations will be required for urban, suburban, and rural settings.

Traffic Operations and Impacts on Nonautomated Roads (Battelle, Calspan, Delco)

- ◆ Incidents on automated roadways may cause serious operational disruptions, requiring timely incident detection and removal.
- ◆ New jurisdictional organizations and cooperative mechanisms will be required to operate and maintain automated facilities.
- ◆ Transportation agencies will need to expand staffs and technical capacity, concentrating more on preventive maintenance of facilities.

BOX 4-2 (continued)

- ◆ Saturation of roads near automated facilities may require geometric design and signalization changes.
- ◆ Queuing of vehicles entering automated facilities may be required but can be handled effectively.

Exit and Entry and Check-in and Checkout (Battelle, Calspan, Delco, PATH, Raytheon)

- ◆ Vehicles may need to check into automated environments while in motion.
- ◆ Vehicles will need to be tested and monitored during operations, not only during exit and entry.
- ◆ Normal and emergency checkout systems will be required.
- ◆ Vehicle and driver readiness will need to be tested. A driver must actively engage the vehicle before checkout, rather than simply being handed the controls.
- ◆ Entry and exit designs will have an important effect on system throughput.
- ◆ AHS designs must recognize that many motorists travel on free-ways for short distances; thus, entry and exit efficiency is critical to motorist acceptance and benefits.
- ◆ Multiple system configurations may be required to accommodate the many differences in street layouts and distances between exit and entry ramps.

Lateral and Longitudinal Controls [Calspan, Delco, Lockheed, Raytheon, Rockwell, Stanford Research Institute (SRI)]

- ◆ Sensors and controls must be able to perform under adverse weather conditions.
- ◆ Magnetic markers or overhead wires are the most promising lateral control technologies.
- ◆ Infrastructure-based systems have the potential to be most cost-effective.
- ◆ Communications among vehicles may not be required if sufficient headway is maintained.

Vehicle Operations (Calspan, Delco, Raytheon, Rockwell)

- ◆ Adding automation capabilities may decrease vehicle reliability by increasing the number and complexity of components that could

BOX 4-2 (continued)

fail. Preventive vehicle maintenance therefore will become even more important.

- ◆ Full automation of vehicles probably will occur in an evolutionary manner, from collision warning devices and emergency controls to automation of routine driving tasks.
- ◆ Software verification, validation, and monitoring in use must be an integral part of the vehicle design process.

Malfunction Management and Safety (Battelle, Calspan, Honeywell, Delco, PATH)

- ◆ Obstacles and nonautomated vehicles entering automated lanes may require barriers.
- ◆ Redundant systems will be necessary.
- ◆ Drivers must not be allowed to relax completely; systems that compensate for the complete inattention of the driver will be expensive.
- ◆ Automation could reduce crashes on urban Interstate highways by 26 to 85 percent, on suburban Interstate highways by 32.5 to 85 percent, and on rural highways by 45.7 to 85 percent.

Commercial Truck and Transit Applications (BDM, Calspan, Delco, Raytheon)

- ◆ It will be difficult for automated facilities to serve intracity trucks because they make frequent stops.
- ◆ The market for intercity bus travel is small.
- ◆ City transit buses, especially express buses, may be the best early candidates for automated applications.

Institutional and Societal Issues (Battelle, BDM, Calspan, Delco, Raytheon, SAIC)

- ◆ There appear to be no insurmountable institutional or societal barriers to automated highway systems.
- ◆ Many of the institutional issues related to automated highways are similar to those of road building in general.
- ◆ If lanes must be dedicated to automated vehicles and vehicle instrumentation is expensive, equity issues will arise.
- ◆ Moderate-income commuters may be the best early candidates for using automated systems.

In retrospect, it is now evident that too little attention was given at the analysis stage to examining the ultimate goal of the program—to specify a preferred system in less than a decade—as well as the way this next phase of the research program would be implemented (through a predetermined public-private consortium).

Systems Definition Phase

With the legislated 1997 deadline for a fully automated highway system approaching, DOT sought to establish a new kind of research and development program that could meet the deadline and continue with the specification, testing, and deployment of a fully automated highway system. DOT issued a Request for Applications in December 1993 seeking the creation of a public-private research consortium that could pool financial resources, technical expertise, and marketplace experience (DOT 1993). DOT anticipated that a national consortium committed to long-range research and drawn from industry, academe, and government agencies would bring continuity and visibility to the program and provide the leadership and insights needed to develop and deploy a fully automated highway system (Bishop and Lay 1997, 69).

DOT was specific in its intention, delineating the structure, methods, and work plan of the proposed consortium. Its Request for Applications prescribed what kinds of participants should be included in the consortium, how the consortium should be organized to involve members and elicit the participation of nonmembers, and how the program would be managed and overseen by the DOT. Emphasis was placed on ensuring the participation of at least one leading organization from various segments of the highway, vehicle, electronics, and communications industries; these “stakeholder” industries were expected to have an important role in the design, construction, deployment, and operation of fully automated systems. Having prominent organizations from these stakeholder groups in the consortium would aid DOT in building enthusiasm for the development and deployment of a fully automated highway system.

DOT outlined six milestones to provide direction for the work plan devised by the selected consortium (DOT 1993, 16):

1. *Establish performance and design objectives* (e.g., expected traffic operating speeds).
2. *Demonstrate proof of feasibility*, fulfilling the congressional mandate for a demonstration and establishing technical feasibility [but not demonstrating a prototype of a preferred system, which was scheduled to occur later in the program].

3. *Identify and describe multiple feasible system concepts*, including factors that should be used to evaluate them (such factors should include institutional and legal issues assessments, technology analyses, and system costs and benefits).
4. *Select a preferred system configuration*, using a thorough, objective process that involves the participation of major stakeholders.
5. *Conduct prototype tests* of major system functions such as steering, braking, lane changing, and malfunction management.
6. *Prepare documentation* of preferred system specifications, implementation standards, scenarios for evolutionary development and deployment, and projected costs and benefits.

The Request for Applications also called for an organization and management structure in which DOT would offer broad policy guidance and consortium participants would make decisions based on a consensus process in which no single stakeholder category would have a disproportionate influence. DOT also required an active outreach effort to elicit the views and involvement of nonmembers. A public relations program was encouraged to foster interest in the development and deployment of fully automated highway systems. Members of the consortium would be expected to pay at least 20 percent of the costs of the program; DOT would pay the remaining costs, which were budgeted at an average of approximately \$20 million per year for 7 years.

Two consortia responded to the request. One was led by General Motors Corporation (GM) and the other by TRW, Inc. The nine-member GM team (Box 4-3) was considered better qualified largely because of the range of prominent stakeholders in its membership. After a period of negotiation, NAHSC began its work in the fall of 1994.

NATIONAL AUTOMATED HIGHWAY SYSTEM CONSORTIUM

Thus, NAHSC was formed with a set of milestones in place, an organizational and management framework outlined, and the results of precursor studies that could be built upon. Indeed, several organizations on the precursor study teams were members of the consortium. In accordance with the program goals established by DOT, NAHSC's stated mission was as follows:

Specify, develop, and demonstrate a prototype automated highway system. The specifications will provide for progressive development that can be tailored to meet regional and local transportation needs. The Consortium will seek opportunities for early introduction of vehicle and highway automation technologies to achieve early benefits for all surface transportation users. The NAHSC will incorporate public and private stakeholder views to ensure that the AHS is economically, technically, and socially viable. (NAHSC 1997a, Appendix A)

BOX 4-3: CORE MEMBERS OF NAHSC AND THEIR SPECIALTIES

- ◆ Bechtel Corporation—infrastructure and environment
- ◆ California Department of Transportation (Caltrans)—infrastructure development and highway operations
- ◆ Carnegie Mellon University—vehicle robotics
- ◆ Delco Electronics—vehicle development
- ◆ General Motors—vehicle development
- ◆ Hughes Electronics—communications and systems engineering
- ◆ Lockheed Martin—system integration
- ◆ Parsons Brinckerhoff, Inc.—traffic engineering
- ◆ University of California Partners for Advanced Transit in Highways (PATH/UC Berkeley)—advanced vehicle control

Organization and Process

The consortium defined a series of tasks—accompanied by designated task leaders, teams, timelines, and detailed work plans—to achieve the six milestones assigned by DOT. Task teams were drawn from each of the member organizations. The consortium also instituted an organizational structure and a set of procedures to ensure that outreach efforts required by DOT were undertaken. NAHSC established an Internet site and published a newsletter to expand its reach to the general public. An associates program was established to provide an avenue for involvement by and input from a range of potential automated highway system users, industries, and transportation agencies; more than 125 organizations were listed as participants in the associates program by 1997. Associates were informed about NAHSC work in progress and, in turn, were expected to provide the consortium with constructive input and information about their own related research activities. Associates ranged from large multinational corporations to individual consultants and were drawn from state and local government, the motor vehicle and electronics industries, and public transit and commercial trucking, as well as other transportation system users, suppliers, and operators.

When NAHSC began its work in early 1995, it recognized the challenge involved in coordinating the work of organizations with varied interests,

expectations, and corporate cultures. Based on guidance provided by DOT, the consortium organized its management into a three-tiered system (Figure 4-2). Broad policy guidance was to be provided by a Policy Steering Board consisting of a senior DOT representative (from the ITS program office) and top executives from each of the nine core members of the consortium. This board was intended to meet at least annually. A Program Management Oversight Committee was established to report to the steering board and to meet more frequently (about every two months) to address management issues. The oversight committee would consist of senior managers from each of the nine core members and nine independent members selected by associate participants; a DOT representative also would be appointed to the oversight committee. Most major decisions having to do with program direction, budgeting for specific tasks, and funding levels for individual members would be made by consensus of the oversight committee.

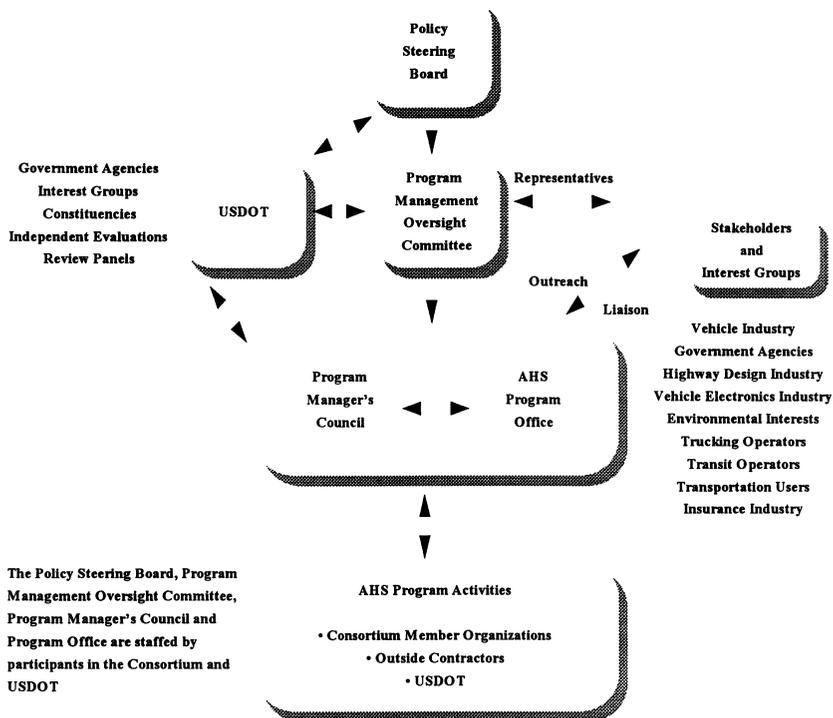


FIGURE 4-2 Management structure of NAHSC (NAHSC 1997a, 21).

Building a consensus often involved an iterative process that required frequent meetings and communications among program managers (Bishop and Lay 1997). To facilitate this process and provide day-to-day management, a Program Manager Council was formed; this council consisted of the NAHSC program manager, the FHWA program manager, and site managers from each of the core members (sometimes supplemented by associate participants). Task assignments, involving teams consisting of analysts from several member organizations, also were designed to foster consensus-building and cooperation. Additionally, the consortium sponsored numerous workshops and conferences in which outside experts and other interested parties were invited to participate. A stakeholder relations and public affairs program was established to develop consensus among stakeholders and include stakeholders in the development of automated highway system concepts; significant emphasis was placed on marketing the program through public and media relations (NAHSC 1997a, 54–55).

Activities

NAHSC had several tasks to pursue. The ultimate goal of most of these tasks was to identify a feasible full automation concept, culminating in the prototyping and testing of a fully automated highway system. Related to this goal, but a major goal in itself, was the successful undertaking of the congressionally mandated automated highway system demonstration in 1997. The demonstration (held in San Diego, California, in August 1997) raised the visibility of the program and gave NAHSC members a near-term objective (see Box 4-4 for a brief description). It also required much of the consortium's attention and resources, however. Figure 4-3 shows major funding items in the NAHSC budget for fiscal year 1997, when much of the organization's resources were dedicated to the demonstration. Although the demonstration

**BOX 4-4: SUMMARY OF SCENARIOS PRESENTED
DURING NAHSC'S 1997 PROOF OF TECHNICAL
FEASIBILITY DEMONSTRATION IN SAN DIEGO,
CALIFORNIA**

NAHSC's August 1997 "Proof of Feasibility Demonstration" was held on a 7.6-mi (12-km) section of HOV lanes on Interstate 15 near San Diego. The lanes were separated from the main north- and southbound lanes of I-15 by concrete barriers. The most significant physical modification to the highway was the addition of several thousand magnets

BOX 4-4 (continued)

in markers embedded in the center of the lanes. Communications equipment was installed along the roadside.

The following scenarios (among others) were presented not as prototypes of an automated highway system but to demonstrate alternatives for providing automated highway travel. Rides on the demonstration vehicles were offered to the public. Riders were surveyed for reactions and feedback, intended to be used by NAHSC in its subsequent efforts to select a preferred system.

Free-Agent, Multi-Platform Scenario

Carnegie Mellon University teamed with the Metropolitan Transit Authority of Harris County (Houston Metro) to demonstrate vehicle-based automation technologies in multiple vehicle platforms (bus and passenger car). Obstacle avoidance, collision warning, and automated lane-change and passing maneuvers were demonstrated using side- and rear-looking sensors.

Platooning Scenario

University of California researchers teamed with Delco Electronics, General Motors, and Hughes to equip eight Buick LeSabres with computers, actuators, sensors, and other instruments to demonstrate the feasibility of automated vehicles operating in platoons to maximize highway throughput. The vehicles traveled in a single-file formation guided by magnets embedded in the pavement. The vehicles accelerated, decelerated, and performed passing maneuvers and coordinated stops to avoid obstacles.

Alternative Technology Scenario

Researchers from Ohio State University equipped four miles of the demonstration lanes with radar-reflective tape. Radar and camera-based vision systems were used to provide longitudinal and lateral control of two automated cars, which performed passing maneuvers using the system.

Evolutionary Scenario

This scenario was intended to show how full automation could evolve from partial-automation technologies and other intelligent vehicle features. Toyota equipped vehicles with sensor and surveillance features that gave the driver obstacle, lane-departure, and blind spot warnings. These features were then combined with adaptive cruise control and other systems to coordinate fully automated driving by two vehicles.

accounted for approximately 15 percent of the consortium's total expenditures over the three full years of the program, it was a particularly significant expense item in view of shortfalls in federal funding. Figure 4-4 shows the original budget for federal funds, including the funding shortfalls that occurred in two of the three years following program inception.

Apart from the demonstration, the consortium's activities centered on identifying and evaluating alternative fully automated highway system concepts. NAHSC planned to examine alternative concepts from a broad perspective first, then narrow its attention to the most promising concepts. Some of the technical and practical issues associated with fully automated highway systems had been explored in the precursor studies; the consortium expected to build on these efforts by employing similar methods, including simulations, modeling, and workshops with outside experts and stakeholders.

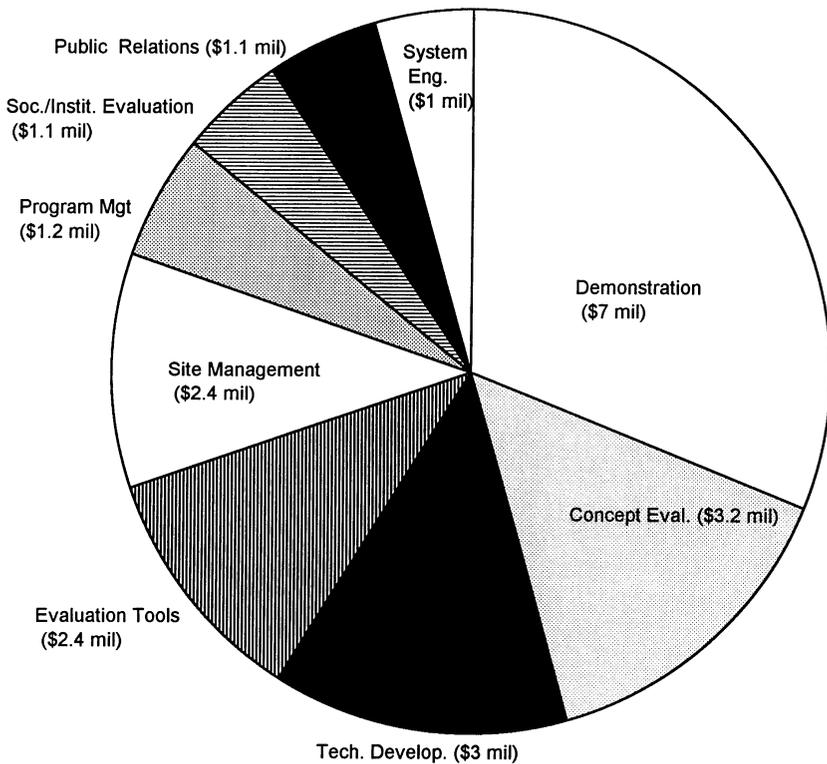


FIGURE 4-3 NAHSC FY 1997 budget by major activity using federal funds.

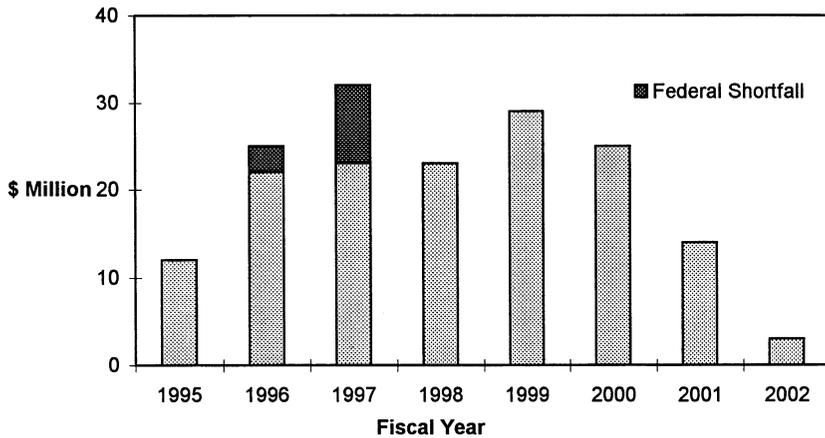


FIGURE 4-4 NAHSC original program budget, federal share (data provided by NAHSC).

(Workshops and conferences sponsored by NAHSC, with issues covered, are listed in Box 4-5.)

Key Findings

NAHSC reported the results of these efforts in June 1997, just before the San Diego demonstration (NAHSC 1997b). The consortium provided analyses of several fully automated highway system concepts (e.g., fully automated vehicles operating on dedicated lanes, in mixed traffic, and in platoons on dedicated lanes) with respect to their effects on highway throughput and travel time, safety, and infrastructure costs. Results from preliminary assessments of societal and institutional issues also were offered, as were perspectives from transportation agencies, users, and industry experts consulted in conferences and workshops.

Throughput

Computer models were developed to determine the effect of alternative fully automated highway system concepts on vehicle throughput and travel times. Automated systems were compared with nonautomated (manual) systems. Different scenarios were developed to vary vehicle spacing, speed, levels of vehicle cooperation, and other characteristics of automated systems.

BOX 4-5: WORKSHOPS SPONSORED BY NAHSC, 1995–1997

*Opportunities for Participation Workshop, Sterling Heights, Michigan,
March 1995*

This public workshop sought to identify people and organizations interested in the research program and provided information about opportunities to participate. The consortium organization and process were explained.

*AHS Objectives and Characteristics Workshop, Fort Lauderdale,
Florida, April 1995*

The purpose of this workshop was to clarify the consortium's objectives and elicit the perspectives of stakeholders from transportation agencies, industry groups, and users.

*Systems Concepts Evaluation Workshop, San Diego, California,
October 1995*

This workshop provided an overview of AHS program status and system concepts and objectives being developed. The consortium presented candidate concepts. Stakeholder participation was encouraged to ensure that the process included appropriate evaluation criteria and concepts that addressed needs.

*NAHSC Stakeholder Concept Downselection Forum, Boston,
Massachusetts, May 1996*

Participants were invited from several stakeholder groups to select associate representatives to serve on the NAHSC Program Management Oversight Committee. Opportunities for actively involving associates and other nonmembers were explored.

*Develop Initial Suite of Concepts Workshop, San Diego, California,
June 1996*

This workshop presented the consortium's initial assessment of alternative AHS concepts, along with concepts independently developed by contractors, to state and local highway and transit agencies; metropolitan planning organizations; electronics, vehicle, and highway design firms; insurance and financial organizations, and environmental interest groups. Participants provided feedback on each concept.

BOX 4-5 (continued)

AHS and Land Use Conference, Pittsburgh, Pennsylvania, August 1996

Several commissioned papers were presented. These papers discussed automated highway systems and the local planning process, impacts on urban land use and metropolitan form, and the practical effects of automated highway systems on urban traffic patterns.

Downselect System Configurations Workshop, Minneapolis, Minnesota, September 1996

This workshop was designed to begin the process of refining AHS concept definitions. Attributes of alternative configurations were examined with respect to meeting stakeholder needs. Participants were more interested in discussing the value of automated highway systems in general than the relative value of alternative configurations. Developments in partial automation technologies also were of greater interest than the plan for full automation.

Joint Workshop on Liability Issues, Washington, D.C., February 1997

This 2-day workshop, cosponsored by the American Association of State Highway and Transportation Officials, examined liability issues associated with automation of vehicles and highways. Federal and state transportation officials, vehicle and product manufacturers, and plaintiff and defense attorneys participated in an effort to identify critical liability issues that could hinder AHS development and deployment.

NAHSC Stakeholder Needs and Services Forum Report, Washington, D.C., June 1997

Conducted in conjunction with the ITS Annual Meeting, this workshop involved technical breakout sessions organized to explore the needs and perspectives of consumers, commercial vehicle operators, transit providers, and highway system operators. Crosscutting issues also were discussed.

(Designed as a preliminary assessment, the models assumed light-duty vehicle traffic only and no intermediate entrance and exit points between the origin and destination of traffic flows). Results from the models suggested that platooning vehicles operating on dedicated travel lanes offered the greatest potential for throughput gains (NAHSC 1997b, 3–4). The maximum throughput of platooned vehicles operating on dedicated lanes was found to

vary from 2,300 to 11,000 vehicles per hour per lane (vphpl) (the highest values were for larger platoons). These figures are 1 to 5 times the throughput assumed for manual traffic (assumed to be 2,200 vphpl). By comparison, the maximum throughput for nonplatooned (automated) vehicles operating on dedicated lanes ranged from 1,500 to 5,000 vphpl (0.7 to 2.3 times the flow rate of nonautomated highways). Other concepts, such as automated (nonplatooned) vehicles operating in mixed traffic with manually driven vehicles, suggested little potential for throughput gains. Additional work was being undertaken at the time of this study to determine how the inclusion of truck traffic and merging and maneuvering at intermediate freeway exits and entries would affect throughput capacity.

Safety

Computer analyses of various braking scenarios (such as when the lead vehicle in a platoon fully engages its brakes and the following vehicles respond) found that cooperating automated vehicles (i.e., fully automated vehicles communicating and interacting with one another) would be significantly safer than vehicles driven manually under the same circumstances (i.e., at similar speeds and following distances) (NAHSC 1997b, 4). One analysis indicated that a nonplatooned but highly cooperative automated vehicle would be several times less likely than a manually driven vehicle to collide with a lead vehicle. Moreover, collisions involving these automated vehicles would tend to occur at lower speeds, thereby reducing the potential for severe collisions. The relationship between speed, safety, throughput, and the degree of intervehicle cooperation (e.g., platooning or nonplatooning) also was investigated. Though only a few parameters and assumptions could be varied, results from the models suggested several trade-offs between throughput and safety. At most throughput levels, cooperating (nonplatooned) fully automated vehicles collided less often than did platooned vehicles. Platooned vehicles, on the other hand, experienced fewer high-speed collisions. Combining collision probability and speed at collision, these preliminary analyses suggested that platooned vehicles would offer the greatest safety potential at the highest throughput levels (i.e., when throughput exceeds 3,500 vphpl).

Infrastructure Costs

Estimates of automated highway system infrastructure requirements in urban areas suggested that the costs involved in constructing dedicated travel lanes for automated vehicles would vary greatly from site to site but would be similar in magnitude to the cost of building high-occupancy-vehicle

(HOV) lanes. Separate entrance and exit ramps would be required to accommodate automated vehicles; in comparison with conventional highways, however, less overall right-of-way would be needed because fewer lanes would be required to carry comparable traffic volumes (assuming that fully automated systems can carry twice the traffic of conventional lanes, thereby requiring construction of half as many lanes (NAHSC 1997b, 5).

Societal, Environmental, and Institutional Aspects

In evaluating alternative public- and private-sector roles in owning and operating fully automated highway systems, as well as the environmental and tort liability issues that are likely to arise, NAHSC concluded that many of these issues are not unlike those now faced by the public and private sectors with regard to building conventional highways and vehicles and that many of these issues would be resolved through similar political, legal, and market processes. Others would need to be examined more carefully and thoroughly as the NAHSC program proceeded. National standards would be needed in areas such as sensing, communications, and driver interfaces to foster development and commercial introduction. Discussions in a workshop of land use experts led NAHSC to conclude that fully automated highway systems would have only marginal effects on land use because transportation infrastructure and land use patterns already are well established. A study sponsored by NAHSC estimated that platooned vehicles would reduce fuel use by up to 25 percent per vehicle mile; aggregate fuel and emissions impacts from changes in total vehicular travel were not reported (NAHSC 1997b, 6).

Study Committee Conclusions

The study committee would have benefited from more objective syntheses and summary evaluations of the consortium's technical and analytical findings. In the absence of such information, it was not possible in this study to assess the consortium's findings and conclusions in a comprehensive way. Even a cursory review of the consortium's work, however, raises questions about objectivity. The conclusion that tort liability, environmental, and transportation infrastructure issues associated with automated highways would be similar to those associated with conventional highway systems seems especially optimistic and highly conjectural based on workshop discussions. Close examination of the workshops sponsored by the consortium (Box 4-5), fails to reveal how such conclusions were reached. Experts participating in a 2-day workshop on land use impacts, for instance, are described by the consortium as concluding that automated highway sys-

tems “would have minimal impact on land use since it will be a relatively small part of a well-established surface transportation system” (NAHSC 1997b, 6). The draft report on this activity, however, does not offer such a summary assessment or any other indication that such a consensus had been reached (NAHSC 1997c). Throughout, the consortium’s work tends to selectively emphasize findings that are favorable to early development and deployment of automated highway systems and minimize those that are not.

At a more fundamental level, however, it is questionable whether NAHSC could have provided an objective and thorough assessment in light of its dual role as evaluator and promoter of fully automated highway systems. Not only was the consortium directed to identify a preferred fully automated highway system from technical and societal standpoints, it also was expected to build support for and ultimately select a system for development and implementation. Separating and balancing these two often conflicting roles proved difficult. For instance, NAHSC recognized early on that one of the important issues it would need to address was whether fully automated vehicles could share travel lanes with manually driven vehicles. The consortium’s traffic throughput and safety assessments suggested that fully automated vehicles operating in mixed traffic would provide little, if any, gains in highway capacity and safety (NAHSC 1997b, 8). On the other hand, many state transportation officials and other stakeholders had expressed concern about the cost and practicality of building or converting lanes to accommodate fully automated traffic (NAHSC 1996). NAHSC therefore was reluctant to eliminate the mixed-traffic concept (the concept with minimal infrastructure requirements), despite its early technical findings (NAHSC 1997b, 7–9).

The conflict inherent in this dual role as evaluator and promoter also was evident in the consortium’s uneven attention to issues. NAHSC focused much of its effort on investigating the technical means of automating driving, such as technologies that could support obstacle detection, platooning, and lane-keeping. Transportation agencies and other stakeholders emphasized the need to better understand the many nontechnological issues associated with development and deployment of fully automated systems—such as liability issues, the role of the public and private sectors in deployment, environmental effects, and other socioeconomic considerations (NAHSC 1996). Although the consortium had planned to address these issues early on, its initial work proved cursory. The breadth and complexity of these nontechnological issues became increasingly evident, but the consortium did not develop insights into how these issues might be better understood and addressed to facilitate the early specification of a fully automated highway system.

These early analytical difficulties, along with the mixed responses received from stakeholders, were indicative of the challenges that would lie ahead in identifying and reaching consensus on a preferred fully auto-

mated highway system. Moreover, although DOT program managers were active in the day-to-day operation of NAHSC, they may have lacked the distance needed to reflect on the consortium's early findings and experiences. This problem is not uncommon; it is the reason that other public-private consortia—most notably the Partnership for a New Generation of Vehicles (PNGV)—have been subjected to, and benefited from, periodic third-party reviews of program plans, accomplishments, and management procedures.¹

An example of a research gap that is apparent in the consortium's work—and one that might have been underscored by an outside review—is the absence of human factors assessments. This gap is explained in part by DOT's early decision to undertake a separate human factors study during the precursor phase of the National Automated Highway System Research Program. Congress had mandated in ISTEA a study of the "human-machine relationship" as it relates to fully automated vehicles and highways. DOT funded a 3-year human factors study by Honeywell, Inc.; most of Honeywell's work was completed before NAHSC began its work, however. Incorporating this early human factors work into the subsequent efforts proved problematic because the kinds of fully automated highway system design concepts being investigated by the consortium changed over time (Neale et al. 1996, 3–4). Thus, the human-machine relationship received limited attention under the NAHSC program.

RECENT DEVELOPMENTS

The ISTEA reauthorization process compelled DOT to examine critically the experience of the NAHSC program and its prospects for achieving its mission. In early 1997, DOT indicated its intention to focus on the implementation of nearer-term, partial automation technologies, significantly de-emphasizing the selection of a preferred system for full automation.

When NAHSC was informed of this change of direction in the spring of 1997, it faced a significant challenge: to substantially revise its work plan and procedures to conform with the new emphasis on evolutionary development and implementation of nearer-term, partial-control technologies. The consortium's composition, internal allocation of funds, outreach programs, and decision-making process were devised for a much different mission—one that would require consensus building to identify and build stakeholder sup-

¹ The PNGV research program, initiated in 1993, is a collaboration between major U.S. automobile makers and the federal government to develop a vehicle prototype that can achieve up to three times the fuel economy of current vehicles. A National Research Council committee has conducted three reviews of the program and is undertaking a fourth.

port for the deliberate advent of a fully automated highway system. Moreover, the consortium was engrossed in planning for a demonstration of fully automated vehicle and highway technologies, as originally instructed by DOT in response to the congressional mandate. Consequently, the consortium responded slowly, and with some reluctance, to DOT's revised priorities. By the summer of 1997, NAHSC had elected to postpone its original plan to select a fully automated highway system, focusing instead on potential candidates for early application of fully automated systems, such as express buses, snowplows, and truck convoys (see Box 4-6). NAHSC has since assisted in staging additional, smaller-scale automated highway technology demonstrations in Arizona (on a test track) and in Houston, Texas, on transit buses.

The study committee review was conducted in the midst of these developments. In December 1997, however, DOT indicated its intention to withdraw funding for NAHSC.

BOX 4-6: EARLY AUTOMATED HIGHWAY SYSTEM APPLICATION SCENARIOS DEVELOPED BY NAHSC

Automated Bus Movement in Maintenance Areas

Before automated buses were used on passenger routes, they would first operate automatically in the maintenance yards, which would offer a low-speed, controlled environment for evaluation and experience. A fixed route could be marked (e.g., by magnetic markers, magnetic stripes, or painted lines) within maintenance stations. The specially equipped buses would follow the route at low speed, stopping at different stations for maintenance tasks.

Automated Snowplows

Sensors would allow snowplows to sense the edge of the road and parked cars in heavy snow and automatically maintain a proper distance from them. The sensors also would keep plows on the road, guided by signals fed from lane sensors and side vehicle detectors. Problem roads could be instrumented with markers that could be detected through heavy snow. The driver could maintain longitudinal (throttle and brake) control, while the automated system would maintain lateral control (steering). This approach would offer a low-speed, controlled environment (lone vehicle and specially trained driver) for early evaluation and experience.

BOX 4-6 (continued)*Truck Convoy with Driver in Leading Truck*

This possible precursor to platooning systems would involve a lead truck driver, with assistance from automation technologies, controlling the driving of several trucks in a convoy. The application would be appropriate for fleets, in which a team of drivers could take turns in leading the convoy and resting. The lead driver would be subject to alertness monitoring and awakened by an alarm if drowsy. Failure to respond would bring the vehicle and convoy to a stop. Also, all vehicles in the convoy could have sensors and logic to determine whether a lane change is safe, and the results would be communicated to the lead vehicle. Before the convoy could change lanes, the lead driver would activate the signal; all vehicles in the convoy would have to respond that it was safe to change lanes.

Precision Bus Docking

Automation could position a bus precisely along a curb, assisting with wheelchair access and preventing tire damage. The driver would first maneuver the bus into the general loading area, then turn control over to automation. Sensors would determine the lateral distance to the curb, front and rear, and the longitudinal distance to the end of the bus loading area. Automation would steer the bus toward the curb and straighten it out to position both front and rear of the bus within the prescribed distance of the curb, with the wheels straight. When properly docked, the bus would stop, open its doors, and revert to manual control. This system could provide experience with technologies envisioned for lane-change collision avoidance systems.

Automated Container Movement (within terminal)

Resembling an “automated” forklift, this specialized application would use vehicle automation technologies to move containers to the next state or to storage within rail-, truck-, or shipyards or to other centralized facilities. Benefits would include labor savings and high accuracy. The origins and destinations of containers could be dynamically reconfigured with high precision. The automated forklifts would move containers to the proper destinations safely (requiring some combination of protected area and obstacle detection) and with high lateral and longitudinal accuracy (requiring preview detection schemes).

BOX 4-6 (*continued*)

Interterminal Passenger Shuttle

Several airports have driverless (rubber-tire) shuttles that move on fixed guideways between terminals. A similar system of automatically driven shuttles could be employed on “dedicated” ways with more flexibility. The drivers of these shuttles would be able to resume manual control at a few designated exits but use automation for longer segments. This early form of full automation would operate in a controlled environment, yet offer experience and insights about potential problems.

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ABBREVIATIONS

DOT	U.S. Department of Transportation
FHWA	Federal Highway Administration
NAHSC	National Automated Highway System Consortium

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5

KEY DISCUSSION POINTS AND FINDINGS

Synthesized in this chapter are the key discussion points and findings in this report, which underpin the study committee's responses to the questions in Chapter 1. These findings are organized according to the chapters from which they are drawn.

BACKGROUND (CHAPTER 2)

Interest in fully automated driving extends back more than 50 years. Early researchers anticipated the planned advent of fully automated, hands-off, feet-off vehicles and highway systems that would greatly improve the comfort and convenience of motor vehicle travel.

More recently (starting in the 1980s), burgeoning interest in automated driving coincided with the growth of interest in intelligent transportation systems (ITS) generally. As part of ITS research and development efforts, attention has been given to systems that can warn a driver of a potential collision, possibly take control of a vehicle in an emergency, or automate certain driving (tasks such as maintaining a safe following distance from other vehicles in traffic). Developments in other types of ITS, such as route guidance and traveler information systems, often have been viewed as complementary, with the potential to merge eventually with crash avoidance systems and other partial-automation features to provide fully automated driving.

The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) called for early prototype development and testing of a fully automated vehicle and highway. This mandate prompted the U.S. Department of Transportation (DOT) to create the National Automated Highway System Research Program. The goal of the program was to develop specifications for a preferred fully automated highway system concept that would provide the basis for future development of supporting vehicle and highway technologies. DOT planned to devote approximately 10 percent of its ITS research and development budget to this multiyear effort.

To pursue these goals, DOT established the National Automated Highway System Consortium (NAHSC). This consortium consisted of nine leading organizations from academe and the public and private sectors, including representatives from the vehicle, highway, electronics, and communications industries. This collaborative approach—in which the federal government was expected to pay 80 percent of program costs—was chosen to expand the program's expertise, resources, and perspective. A diverse and prominent membership also was considered essential to building interest in and support for the early development, testing, and deployment of fully automated systems.

NAHSC was directed to gain a better understanding of the range of full-automation concepts, as well as the needs of prospective developers and users of these systems, termed "stakeholders." The consortium was expected to stage the demonstration of automated vehicles and highways by 1997. Its ultimate goal was to specify, develop, and test a preferred fully automated highway system.

NEEDS, CONCEPTS, AND ISSUES (CHAPTER 3)

The need to further reduce the incidence and severity of motor vehicle crashes and the need to increase the efficiency and capacity of the highway system offer compelling reasons for ITS research and development in general. These same needs underlie efforts to develop fully automated vehicle and highway systems.

Demand for motor vehicle travel has grown, and continues to grow, at a rapid pace. By comparison, the size of the road system is relatively static. Expanding highway capacity to keep pace with travel demand is increasingly difficult and costly. State and local transportation agencies are finding it impractical to build more highways and travel lanes in many urban areas. ITS developments such as electronic toll collection, computer-synchronized traffic signals, and travel information systems are helping to improve the operations and efficiency of highway networks around the country. Uncertainty about whether the additional capacity gained from these efforts will be sufficient has spurred interest in fully automated vehicle and highway systems.

Impressive gains have been made in highway safety over the past three decades. One area that has been most difficult to address, however, is the large share of crashes caused by driver error. Advanced technologies, such as collision warning systems that would aid motorists and possibly take control of the vehicle in an emergency, could help reduce crashes attributable to driver error and poor performance. The safety potential of these systems remains unclear, especially because of the need to integrate their performance with human factors such as the behaviors and capabilities of drivers.

Even less certain is the overall safety effect of fully automated driving, which would depend on how and where these systems were deployed as well as assurance of their safe operation. The safety potential and reliability of fully automated systems and associated human factors issues have not received significant research attention.

Some advanced vehicle systems—possible precursors to full automation of routine driving tasks—are far along in development, and a few (such as radar-based collision warning systems) have been introduced in the marketplace. Systems that support fully automated driving presumably would incorporate many of these precursor features. Many technology combinations and configurations are possible, though their feasibility remains uncertain. Full-automation concepts currently being explored range from those that would involve autonomous vehicles driven automatically, primarily through the use of in-vehicle systems, to those that would involve close communications and cooperation among vehicles and between vehicles and highway infrastructure. An example of the latter concept would be platoons of vehicles operating at high speeds and in close spacing on lanes dedicated to fully automated travel; such systems would yield substantial gains in traffic throughput.

Alternative concepts of full automation raise different technical, institutional, environmental, and economic issues. No single concept is likely to be most suitable with regard to all of these issues; trade-offs undoubtedly would be required. Understanding all of the issues and ramifications of different automation concepts and determining the trade-offs that would be acceptable to users and providers of the system present significant challenges to early identification of a preferred fully automated highway system concept.

NATIONAL AUTOMATED HIGHWAY SYSTEM RESEARCH PROGRAM (CHAPTER 4)

The National Automated Highway System Consortium was created by DOT in 1994. The composition, structure, and procedures of the consortium were specified by DOT with the goals of staging the congressionally mandated demonstration and identifying and building support for a preferred automated highway system concept. DOT recognized that early specification of a system would require broad and deep support by transportation users and providers and directed the consortium to develop active outreach and public relations programs. The consortium also was encouraged to make all key decisions by stakeholder consensus.

The magnitude of the consortium's task (to assess the technical as well as the practical feasibility of alternative systems), its dual roles as evaluator and promoter of fully automated highway systems, and the resulting organiza-

tional and decision-making processes combined to present a very difficult challenge. The effort required to undertake the congressionally mandated demonstration and shortfalls in federal funding made this challenge even more imposing.

The consortium nevertheless diligently pursued its charge—staging the demonstration, actively reaching out to the transportation community, and exploring many technical and nontechnical issues regarding the feasibility of alternative automation concepts. These efforts, however, tended to raise many more issues than they resolved, further illuminating the difficulties inherent in specifying and generating support for a fully automated highway system at this early stage. As these difficulties became more evident, the consortium was unable to build significant support for the specification of a fully automated highway system, despite extensive outreach and promotional efforts.

The consortium's ability to reflect on its initial findings and experiences and modify its mission and work plan was limited by its consensus decision-making process, its emphasis on promoting fully automated highway systems, and the absence of independent means of assessing its work and direction. These shortcomings became most apparent when it became necessary—and proved difficult—for the consortium to respond to DOT's changed priorities. Inasmuch as the consortium's mission, organization, and processes were devised with a particular vision of how a fully automated highway system could emerge, its prospects for pursuing a much different vision were limited.

APPENDIX A

SPEECH BY FEDERAL HIGHWAY ADMINISTRATOR RODNEY E. SLATER ANNOUNCING NATIONAL AUTOMATED HIGHWAY SYSTEM CONSORTIUM RESEARCH PROGRAM, OCTOBER 21, 1993

I would also like to extend a warm welcome to each of you for coming to what I believe to be a historic meeting—historic in our efforts to improve safety and mobility of the vehicle highway system and another step forward to this new era for the system.

And what a time to begin. One hundred years ago this month the Federal Highway Administration's predecessor agency, the Office of Road Inquiry, was established to improve the science of road-building in the United States. At this same time the automobile was born. So it is appropriate and symbolic that we kick off this effort this month to improve and evolve the vehicle highway system with this great step forward.

Over the course of these 100 years, automakers and road builders and operators have tended to pursue their own professions separately from each other. In the Automated Highway System we must unite these professions to succeed, using the groundwork laid by the broader IVHS program.

The consortium called for in the AHS effort will involve such cooperation, and unlike previous programs, this is a new partnership between the public and private sectors, in magnitude and in scope. It is not doing business as usual. The President and the Vice President have charged us to reinvent government. The AHS program is right in line with that charge.

In 1893 the horseless carriage was just coming to the attention of road transportation, but it was the beginning of a new era of improved mobility and safety. AHS is a key part of the vision for transportation in the next century, and those of us involved in the program now and over the next few years are critical in helping this new era come to pass. As we involve ourselves in this great endeavor, we will welcome the future. We will embrace it. Yes, we will create it.

Why is the Department of Transportation pursuing this development of AHS so vigorously? Let me share with you my sense of the need for the Automated Highway System and the potential benefits created by the future deployment of this system.

Our current highway transportation system, as effective and as elegant as it is, is at a critical crossroads in its evolution and has started to plateau in its ability to provide significant new operating performance in its present form. The deployment of IVHS technologies will offer substantial performance improvements in this and in coming decades.

However, the benefits to be derived from a mature IVHS system will be limited by the abilities of the person in the driver's seat. This, combined with increasing traffic demand and our nation's desire for greater safety on the roads and lessened environmental impact, compels us—yet, it challenges us—to consider this next major leap: full automation of the driving function.

The automated control of vehicles operating on designated facilities in high-priority traffic corridors clearly holds realistic promise of successfully addressing all of these user needs. We see this high-performance highway system as the next major evolutionary stage of surface transportation.

The mandate given to us in the Intermodal Surface Transportation Efficiency Act of 1991 to demonstrate a prototype AHS by 1997 is an important program milestone. We will proceed beyond that point to select the best possible AHS system configuration, a system which will form the basis for the next major performance upgrade of the vehicle highway system in this country. This process of selection will involve extensive research, development, testing, and evaluation from the technical vantage point, as well as a thorough and realistic assessment of institutional and societal issues which will influence AHS deployment.

Throughout this endeavor, we will aggressively reach out to shareholders and to stakeholders to involve them in the decision-making process, beginning with the establishment of the National AHS Consortium. This consortium—in partnership with FHWA, with NHTSA, and with other members of the DOT family—will be the focal point for this nation's AHS program, and as such we will be seeking to partner with a consortium which represents the key stakeholders: state and local transportation agencies; the vehicle industry; the highway design industry; and the electronics and communications industry.

And in order to tap their creativity, this program will provide significant opportunities for small businesses, disadvantaged businesses, as well as historically black colleges and universities. This is the first Federal Highway Administration solicitation which will include an evaluation factor for small, disadvantaged business participation.

President Clinton has issued a clarion call to rebuild America. In response to that call and challenge, Secretary Peña has established some very straightforward goals for the Department of Transportation, and the Automated Highway System is one of the major initiatives within the federal IVHS program which addresses all of these goals. They total five, and I would like to just mention them briefly.

First, our highest priority is to get our economy moving and to create jobs through strategic transportation investment. Our investment in the Automated Highway System, through the partnership to be further discussed here today, represents a major Department of Transportation research and development program. It will support significant activity and research in the academic sectors of our economy and will spark the creation of significant new markets for private-sector products and services. In short, it provides the opportunity for U.S. industry to stake out a dominant position internationally in the unique technologies that will comprise the future Automated Highway System.

Second, we must ensure that our investments improve daily life by making travel safer and less stressful. As I mentioned earlier, the Automated Highway System offers the potential for dramatic changes in the driving experience, such that safety would be vastly increased and drivers would be free from the stress of driving in heavy, congested traffic. The expected ability of an Automated Highway System to handle large volumes of traffic also creates benefits for the entire road network, relieving stress on the surrounding highways, thereby benefiting all users.

Our third goal: We must develop and apply new technologies that will create new industries. The process has already begun in this program, with the analysis contracts over the last few months totaling almost \$15 million. Thus, the creation of the automated highway industry has already begun.

Several of these firms are defense contractors seeking an opportunity to apply their considerable experience and technology, such as sensors and fail-safe systems and a complex system design, to this new era of research and this new area of research. The automated highway program is perfectly positioned to harness these military technologies and to convert them for civilian use.

Our fourth goal: Our strategic transportation investments should be made in ways that will enhance the environment. The Automated Highway System provides direct environmental benefits over manual control of vehicles, and an important part of the stakeholder outreach effort during the development of the Automated Highway System will be to the environmental community.

And, finally, we must integrate all modes of transportation into a seamless system for moving goods and people. The Automated Highway System is expected to provide a highly effective highway system which can be integrated with other personal and public transportation options to result in a much-improved surface transportation system. The exciting possibilities for such integration are limited only by our imagination and our willingness to think anew.

In conclusion, this administration is committed to harnessing state-of-the-art technology to improve national productivity and our quality of life. Through technology development, transfer and reinvestment and through

national consensus-building, we can, we will—we will—develop an Automated Highway System which will revolutionize our approach to safety and mobility.

We encourage your participation in this great endeavor, knowing that your creating energies and determined efforts will assure that the United States transportation system—both the roads and the vehicles which operate on them—will be safer, more effective, and responsive to the challenges of the 21st century.

It is said that once the mind reaches forth to embrace a new idea, it can never return to its former state. Let us not work without this in mind, and let us not rest until this great work is done.

Thank you.

APPENDIX B

PRESENTERS AND PARTICIPANTS

During the course of the study, the following individuals participated in meetings or made presentations to the study committee:

David Barry, Director, IVHS and Research Programs, National Private Truck Council

Richard Bishop, former Program Manager, Automated Highway System Research, Federal Highway Administration

Stephen Carlton, Acting Program Manager, National Automated Highway System Consortium

Henry E. Dittmar, Executive Director, Surface Transportation Policy Project

Anthony Hitchcock, Consultant

Ralph Hitchcock, Honda Motor Company of North America

Christine M. Johnson, Director, ITS Joint Program Office, Federal Highway Administration

Brian O'Neill, President, Insurance Institute for Highway Safety and Highway Loss Data Institute

Raymond Resendes, ITS Joint Program Office, Federal Highway Administration

James H. Rillings, Program Manager, General Motors ITS Program Manager and former Program Manager, National Automated Highway System Consortium

Bernard Robertson, Vice President, Vehicle Engineering, Chrysler Corporation

Jack Schenendorf, Chief of Staff, Committee on Transportation and Infrastructure, U.S. House of Representatives

William M. Spreitzer, Technical Director, General Motors ITS Program

Peter Staudhammer, Vice President, Science and Technology, TRW Inc.

William Stevens, Technical Director, National Automated Highway System Consortium

Douglas Toms, Honda Motor Company of North America

STUDY COMMITTEE

BIOGRAPHICAL INFORMATION

ARDEN L. BEMENT, JR., *Chairman*, is Basil S. Turner Distinguished Professor of Engineering at Purdue University and Director of the Midwest Superconductivity Consortium. He was Vice President for Technical Resources at TRW, Inc., from 1980 to 1988. Earlier, he was Deputy Undersecretary of Defense for Research and Engineering and Director of the Materials Science Office, Defense Advanced Projects Agency. He previously served as Professor of Nuclear Materials at Massachusetts Institute of Technology and manager of the fuels and materials and metallurgy research departments at Battelle Northwest Laboratories. He is a Fellow of the American Society for Metals International, the American Nuclear Society, and the American Institute of Chemists. Dr. Bement has chaired and served on several National Research Council committees and is a member of the National Academy of Engineering.

HERBERT H. RICHARDSON, *Vice Chairman*, is Director of the Texas Transportation Institute and Associate Vice Chancellor for Engineering for the Texas A&M University System, where he also is Regents Professor and Distinguished Professor of Engineering. He previously served as Chancellor of the Texas A&M University System. Before joining Texas A&M in 1984, he was Associate Dean of Engineering and head of the Mechanical Engineering Department at Massachusetts Institute of Technology. He also was the first Chief Scientist for the U.S. Department of Transportation. He has served on numerous TRB and National Research Council committees and is a past Chairman of the TRB Executive Committee. Dr. Richardson is an Honorary Member of the American Society of Mechanical Engineers and a member of the National Academy of Engineering.

LAWRENCE D. DAHMS is Executive Director of the Metropolitan Transportation Commission of the San Francisco Bay Area. Before joining the Commission in 1978, he was Deputy Director of the California Department of Transportation, and he held numerous positions in the Bay Area Rapid Transit District, including Director of Planning and Marketing, Assistant General Manager of Opera-

tions, and Acting General Manager. Mr. Dahms is a past Chairman of ITS America. He has served as Chairman of the TRB Executive Committee and on numerous TRB and National Research Council committees.

THOMAS B. DEEN is a transportation consultant and former Executive Director of TRB (a position he held from 1980 to 1994). He is former Chairman and President of PRC-Voorhees, a transportation engineering and planning consulting firm with clients worldwide. During the early 1960s, he served as Chief Planner for the design of the Washington, D.C., metropolitan rail transit system. He was Chairman of the Strategic Planning Committee of ITS America, and he is active in the Institute of Transportation Engineers and other transportation engineering organizations. Mr. Deen is a member of the National Academy of Engineering.

JOHN J. FEARNSIDES is Senior Vice President and General Manager at the MITRE Corporation and Director of its Center for Advanced Aviation System Development, which is responsible for aviation and air traffic control research and engineering for the Federal Aviation Administration. Before joining MITRE, he held various positions at the U.S. Department of Transportation, including Deputy Undersecretary, Chief Scientist, Acting Assistant Secretary for Policy, and Acting Administrator of the Research and Special Programs Administration. Dr. Fearnside has served on several Research Council committees and on the Board of ITS America.

MICHAEL M. FINKELSTEIN is principal of Michael Finkelstein & Associates. He previously served as Associate Administrator for R&D, Rulemaking, and Planning and Evaluation for the National Highway Traffic Safety Administration (NHTSA). He also served as Chief of the Highway and Mass Transit Program Division in the Office of the Secretary of Transportation. Mr. Finkelstein received the Gold Medal for Outstanding Achievement from DOT and a Special Award for Appreciation from NHTSA. He is Chairman of the TRB Committee on Transportation Safety Management.

THOMAS D. LARSON is a transportation consultant and former Administrator for the Federal Highway Administration, serving from 1989 to 1993. He served as Secretary of Transportation for the Commonwealth of Pennsylvania from 1979 to 1987. Before entering the government, he was Institute Professor of Civil Engineering at Pennsylvania State University and Director of the Pennsylvania Transportation Institute. Dr. Larson is a past Chairman of the TRB Executive Committee and the Strategic Highway Research Program Executive Committee and served as President of American Association of State Highway and Transportation Officials. Dr. Larson is a member of the National Academy of Engineering.

NANCY G. LEVESON is Hunsaker Visiting Professor of Aeronautical Information Engineering at the Massachusetts Institute of Technology and Boeing Professor of Computer Science at the University of Washington. Her work has focused on building software for real-time systems where failures can result in loss of life or property. Dr. Leveson is a member of the Commission on Engineering and Technical Systems (CETS) of the National Research Council. She has served on several CETS committees; she chaired the Study of the Space Shuttle Software Process and was a member of the CETS study committee on Computers in Nuclear Power Plants. She is a Fellow of the Association for Computing Machinery and was awarded the 1995 American Institute of Aeronautics and Astronautics Information Systems Award.

JOHN E. MAJOR is Executive Vice President, and President of Infrastructure Products, QUALCOMM, Incorporated. Before joining QUALCOMM in 1997, he was Senior Vice President and Chief Technology Officer for Motorola. He led Motorola's efforts to become a global leader in software development and managed the Worldwide Systems Group that developed and manufactured private radio systems for voice and data communications. Mr. Major is chairman of the Electronics Industry Association and a member of the Computer Science and Telecommunications Board of the National Research Council.

ROBERTA J. NICHOLS is a transportation fuels consultant, recently retired from Ford Motor Company. At Ford, she was Manager of the Electric Vehicle External Strategy and Planning Department, Manager of Electric Vehicle External Affairs, and Manager of the Alternative Fuels Department. Before joining Ford, she was a member of the technical staff of the Aerospace Corporation. She is a Fellow of the Society of Automotive Engineers and a Senior Member of the Society of Women Engineers. She has chaired TRB's Alternative Transportation Fuels Committee and serves on other Research Council panels, including the CETS Committee on the Advanced Automotive Technologies Plan. Dr. Nichols is a member of the National Academy of Engineering.

JEROME G. RIVARD is President of Global Technology and Business Development, Harrison Township, Michigan. From 1986 to 1988, he was Vice President and Group Executive, Bendix Electronics, a division of Allied Signal, Inc. He has held several positions in divisions of the Bendix Company, including the Vehicle Controls Department, the Automotive Advanced Concepts Program, the Electronic Fuel Injection Division, and the Engineering Group. He previously worked for Ford Motor Company as Chief Engineer of the Electrical and Electronics Division. Earlier in his career, Mr. Rivard worked for the U.S. Army Ballistic Missile Agency and Vicker, Inc. He is a

Fellow of the Society of Automotive Engineers and the Institute of Electrical and Electronic Engineers. Mr. Rivard is a member of the National Academy of Engineering.

DANIEL ROOS is Associate Dean of Engineering Systems at Massachusetts Institute of Technology. He also is Professor of Civil and Environmental Engineering at MIT; from 1978 to 1985, he was Director of the Center for Transportation Studies. He also directed the Institute's International Motor Vehicle Program and Center for Technology, Policy, and Industrial Development. Dr. Roos served as chairman of the TRB Committee to Assess Advanced Vehicle and Highway Technologies. He received the Frank M. Masters Transportation Engineering Award from the American Society of Civil Engineers in 1989.

WAYNE SHACKELFORD is Commissioner of the Georgia Department of Transportation. In this capacity, one of his accomplishments was the development and operation of the Department's transportation management programs during the 1996 Olympic Summer Games in Atlanta. He is a past president of AASHTO and Past President of the Southeastern Association of State Highway and Transportation Officials. He recently served as Chairman of ITS America. Mr. Shackelford has been active in TRB's Strategic Highway Research Program; he also is a member of the TRB Executive Committee and is its 1998 Vice Chairman.

THOMAS B. SHERIDAN is Ford Professor of Engineering in the Department of Mechanical Engineering and Department of Aeronautics and Astronautics at Massachusetts Institute of Technology. His expertise is in human factors, including modeling and design of human-machine systems for automobile driving, aviation, and other modes of transportation. He is a Fellow of the Institute of Electrical and Electronics Engineering and the Human Factors Society. He has served on committees for the National Research Council, the National Institutes of Health, the National Aeronautics and Space Administration, and the National Science Foundation. Dr. Sheridan is a member of the National Academy of Engineering.

DAVID N. WORMLEY is Dean of Engineering at Pennsylvania State University. Previously he was Professor of Mechanical Engineering at Massachusetts Institute of Technology, where he also served as Associate Dean of Engineering. His research focuses on the dynamic analysis and design of advanced control systems for transportation and other applications. He serves on the editorial board of the *International Journal of Vehicle Mechanics and Mobility*. Dr. Wormley was the 1997 Chairman of the TRB Executive Committee.